



IN-STACK CONTINUOUS MONITORING OF EMISSIONS  
FROM STATIONARY SOURCES

ARB AGREEMENT No. 3-733

A large, hand-drawn graph occupies the background of the page. It features two distinct data series plotted as jagged, continuous lines. The upper series starts at a moderate level, rises to a peak, and then fluctuates at a high level. The lower series starts at a lower level, rises to a peak, and then drops significantly, remaining at a lower level than the first series. Both lines are drawn with a thick, dark ink, giving them a sketchy, field-record appearance.

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### ABSTRACT

A study was performed on the status of technology of continuous monitors for emissions from stationary sources in California. About 700 sources were identified which had emissions of 100 tons/year or more of the contaminants considered (NO<sub>x</sub>, SO<sub>2</sub>, CO, particulates, hydrocarbons), and which were suitable for installation of a continuous monitor.

Systems of stated reliability and moderate cost (\$10,000 to \$20,000) were found to be available from several manufacturers. Direct reading of the mass rate of emissions and electronic data handling and storage were found to be feasible, effective options. Costs were estimated to be about 10% and 25%, respectively, of the basic monitor cost. Examples of specific applications of both in situ and extractive systems were prepared and are presented. For many combustion devices the annual fuel cost savings that could result from continuous combustion control would equal the original monitor system cost. The technology of continuous monitors was found to be well developed based on several years of field experience.

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## 1.0 INTRODUCTION

Continuous measurement and recording of exhaust gas parameters from combustion devices has been routinely performed in many applications. In several of these instances the primary motivation has been economic. By measuring, for example, the oxygen ( $O_2$ ) and carbon monoxide (CO) in the flue gas, on a continuous basis, much more efficient operation of a heater or boiler can be achieved. Many combustion devices routinely operate at CO levels in excess of 2000 ppm<sup>(1)</sup> because of a lack of data or control of this parameter. However, it has been shown<sup>(2)</sup> that reducing the CO level can result in fuel savings on the order of .3% for every 1000 ppm. For a large heater (eg 250 MMB/h) the fuel cost savings alone for the first year would pay for the cost of an oxygen and CO continuous monitor system.

More recently, interest in continuous measurement systems has been focused on pollutant characterization and reduction. Imminent Federal and State regulations<sup>(3,4)</sup> would require the installation of monitors to measure oxides of nitrogen (NOx), oxides of sulfur ( $SO_2$ ), CO, hydrocarbons, reduced sulfur compounds and particulate matter; where those pollutants or the process exceed certain rates. The rates established by the State of California for pollutants are 100 tons/year for all but CO for which 1000 tons/year is proposed.

Reporting and data storage requirements have also been proposed which would place severe demands on manual techniques. For example, the State of California and EPA-proposed regulations both require storage of all data for a two-year period.

Emission measurements to date have consisted mainly of discrete, random sampling with either wet chemical methods or electronic instruments. Several limitations are obvious:

1. Representative operating and sampling conditions are difficult to establish.
2. Emissions can vary considerably, depending on the type of fuel, the load, or process rate.
3. Any violations of existing regulations will usually occur at times other than testing because of the statistically small period of time sampled.

4. Emissions tend to be dependent on combustion device history and operating condition. Thus, measurement at a given point in time will not necessarily be related to a later period.
5. Real time assessment of violations and their correction is not possible.

Recognizing these limitations, and to provide a firm basis for the design of strategies to control emissions from stationary sources, the California Air Resources Board initiated this study to evaluate presently available continuous monitor systems. This program was concerned with complete monitor systems rather than individual instruments or components.

The number and types of emission sources in California exceeding the 100 ton/year limit were determined for the pollutants discussed above. Air pollution damage estimates were made by source category and related to monitor requirements.

Based on this evaluation, questionnaires were sent to manufacturers of continuous monitor systems to obtain information on cost, accuracy, reliability, availability, and other criteria for evaluation of systems to measure and record emissions of specific pollutant combinations. The information provided was evaluated and summarized.

Process computing networks necessary to enable a readout of the true mass flow rate of emissions were designed and cost estimates made.

The data handling and storage requirements were analyzed and several systems identified and cost estimates made.

Finally, examples of continuous monitor installations on typical emission sources were prepared to provide a guide for the potential user who is unfamiliar with this technology.

## 2.0 SOURCE SUMMARIES

### 2.1 Pollutants

The emissions that are the subject of this report are particulates (Part), sulfur dioxide ( $\text{SO}_2$ ), oxides of nitrogen ( $\text{NO}_x$ ), hydrocarbons (HC), and carbon monoxide (CO). A description of these various pollutants, a brief outline of the processes that produce each and control systems that are available to control each are discussed below.

2.1.1 Particulates. Particulate matter includes all dusts, acid mists, smoke, fly ash, etc. In most air pollution control jurisdictions particulate matter is defined as all finely divided liquid and solid material at standard conditions, excluding uncombined water (standard conditions are usually defined as 60 °F and 14.7 psia).

Particulate matter from combustion sources includes non-combustibles (ash) and unburned fuel residues (pyrolysis products), as well as some hydrocarbon compounds and sulfur trioxide (as  $\text{H}_2\text{SO}_4 \cdot 2\text{H}_2\text{O}$ ). Since some hydrocarbons are included both as particulates and in the measurement of total hydrocarbons, some portion of the hydrocarbon emissions are accounted for twice.

Particulate matter from non-combustion sources includes dusts from loading operations, cement manufacture, aggregate drying etc.

In some cases particulate matter is produced concurrently by a combustion and a non-combustion source. For example, in cement manufacturing a mixture of finely divided solid materials is heated by direct contact with a flame. The exhaust gas from this process contains particulate matter from both the combustion process and from particles of the solid material which are entrained in the combustion products.

A large percentage of these materials can be removed by employing control devices such as cyclones, electrostatic precipitators, bag houses, scrubbers, etc.



2.1.2 Sulfur Dioxide. Sulfur dioxide ( $\text{SO}_2$ ) is the major form of gaseous sulfur emissions (the other being sulfur trioxide). The primary source of  $\text{SO}_2$  emissions is from combustion of sulfur containing fuels. A large percentage of the sulfur in fossil fuels is emitted as  $\text{SO}_2$  with a small portion appearing as  $\text{SO}_3$  (up to about 5%) and some appearing in the ash. Another substantial source of  $\text{SO}_2$  is sulfur recovery units at oil refineries.

Sulfur dioxide emissions can be controlled by the use of low sulfur fuels and/or scrubber systems.

2.1.3 Nitrogen Oxides. Nitrogen oxide ( $\text{NOx}$ ) emissions consist of nitric oxide ( $\text{NO}$ ) and nitrogen dioxide ( $\text{NO}_2$ ). Although a small amount of these pollutants are emitted from chemical plants of various types, most  $\text{NOx}$  is emitted from combustion sources.

Combustion processes produce  $\text{NOx}$  by two mechanisms. First, some portion of the nitrogen in the fuel is converted to  $\text{NOx}$ . Second,  $\text{NOx}$  is produced by a thermal process involving the molecular nitrogen in the combustion air.

Emission of oxides of nitrogen can be controlled by selecting low nitrogen fuels, by combustion modification techniques and by employing low  $\text{NOx}$  burners.

2.1.4 Hydrocarbons. Hydrocarbon emissions ( $\text{HC}$ ) consist of vaporized solvents and fuels.  $\text{HC}$  emissions from combustion sources are mostly unburned fuels while emissions from non-combustion sources are primarily evaporated solvents. Since some of these compounds are liquids at ambient conditions, they are also classed as particulate. That is, some of  $\text{HC}$  compounds are measured twice and reported in two categories of pollutants.

Since emissions of hydrocarbons from combustion sources are a result of incomplete combustion of hydrocarbon fuels, they can be avoided by ensuring correct combustion conditions (e.g. sufficient air, correct burner adjustment, etc.). Hydrocarbon emissions from evaporation sources can be controlled by using afterburners, vapor collection systems, or solvent recycling systems.

2.1.5 Carbon Monoxide. The primary source of carbon monoxide (CO) is incomplete combustion of fuels. This pollutant can be avoided by ensuring correct combustion conditions (e.g. sufficient air, correct burner adjustment etc.). Another potentially large source of CO emissions are the fluid catalytic cracking units (FCCU) at refineries. Large amounts of CO are generated in these units when the carbon deposits are burned off the catalyst. In most cases, the CO is burned in a waste heat boiler (CO boiler) to both eliminate the air pollution problem and to recover the heating value of the CO.

## 2.2 Categories of Devices

In order to determine the number of substantial emission sources and the magnitude of emissions of each pollutant, a summary of the EPA National Environmental Data System (NEDS) data base for California was obtained.<sup>(5)</sup> This summary contained information on all devices in the State that emit 25 tons/year or more of any pollutant, and all devices in Los Angeles County that emit 1 ton/year or more of any pollutant. This information provided a basis for making estimates of the emissions from the various categories of sources.

These sources were placed in one of several categories based on the type of industry or product involved. These categories were then subdivided according to the type of process or type of source involved. For example power plant operations were subdivided into Electrical Generation (Combustion) and Fuel Storage and Handling. The purpose was to classify each source, so that some estimate of the type of monitors that are required for all devices in that category could be made.

The preliminary summary of the NEDS data base for California is the only state wide compilation of emissions of all types that is available. However since this summary is preliminary and subject to corrections and additions<sup>(5)</sup>, it is useful only as a rough guide to the types and quantities of emissions from each category. In order to check the completeness and accuracy of the summary, a comparison was made with a very comprehensive survey of NOx emissions in the South Coast Air Basin.<sup>(1)</sup> (The South Coast Air Basin includes all or part of the following counties: Los Angeles, Orange, San Bernardino, Riverside, Ventura and Santa Barbara.)

As Table 2-I shows in most cases there was good agreement between the two surveys. The notable exception is the cement plants. The difference is due in large measure to the absence of emission data for a large cement plant in the NEDS summary. There is some difference in the refinery data also; refinery NOx emissions consistently have been underestimated according to the South Coast Air Basin Study. <sup>(1)</sup>

Table 2-I. Comparison of NOx Emissions Data

Device Category	NEDS Summary NOx Emissions (Tons/yr)	South Coast Air Basin NOx Study (Tons/yr)
Power Plants	42,747	42,243
Refinery	14,698	22,006
Cement	2,120	11,833
Glass	4,385	4,196

Table 2-II summarizes the comparisons between the emission estimates as tabulated the NEDS Summary and the emissions estimated by the various local APCDs.

County	Pollutants	NEDS Summary (Tons/yr)	APCD Estimate (Tons/yr)
Los Angeles <sup>(6)</sup>	Particulates	27,581	21,900
	SO <sub>2</sub>	150,807	76,650
	NOx	101,469	102,200
	Hydrocarbons	187,243	279,225
	CO	3,385	3,650
Orange <sup>(7)</sup>	Particulates	1,207	2,117
	SO <sub>2</sub>	6,474	5,731
	NOx	4,399	8,505
	Hydrocarbons	2,809	18,214
	CO	16	840

Table 2-II. Comparison of NEDS Summary with Local APCD Emission Estimates (cont.)

County	Pollutants	NEDS Summary (Tons/yr)	APCD Estimate (Tons/yr)
San Bernardino <sup>(8)</sup>	Particulates	10,385	13,104
	SO <sub>2</sub>	17,325	15,221*
	NOx	35,455	28,288
	Hydrocarbons	3,067	9,527
	CO	5,190	4,782
Santa Barbara <sup>(9)</sup>	Particulates	3,117	5,731
	SO <sub>2</sub>	56	183
	NOx	177	3,760
	Hydrocarbons	20	10,184
	CO	17	5,840

In most cases the two estimates are similar, indicating that the large emission sources account for a very high percentage of the total of the 5 pollutants. (The estimates in the table are for stationary source emissions only.)

Table 2-III summarizes the emissions from sources which emit 100 tons/year or more of each pollutant. Only emissions of 100 tons/year or more were counted. For example, if a given device emits 100 tons/year of NOx and 90 tons/year of SO<sub>2</sub>, only the NOx was tabulated.

It was assumed that the 100 ton/year limit of the EPA or State of California was the minimum below which no monitor would be required. Using this limit, the following fractions of the total estimated emissions from substantial sources would be monitored:

Particulates	88%
SO <sub>2</sub>	84%
NOx	81%
Hydrocarbons	80%
CO	94%

\* SO<sub>x</sub>

TABLE 2-III  
SUMMARY OF EMISSIONS BY CATEGORY

Device Type	tons/year					Number of devices in category emitting 100 tons/year or more of any pollutant
	Particu- late	SO <sub>2</sub>	NOx	HC	CO	
Power Plant Operations	9,057	69,710	120,221	18,123	4,017	130
Electrical Generation	9,057	69,710	120,221	16,283	4,017	125
Fuel Handling and Storage	0	0	0	1,840	0	5
Gas and Oil Operations	5,698	119,242	47,758	78,666	146,719	212
Heaters and Boilers	2,045	38,399	34,396	2,139	1,110	64
Compression & Transportation	0	0	4,025	3,898	127	14
Storage and Handling	0	790	0	57,981	0	91
Miscellaneous	3,653	80,053	9,337	14,648	145,482	43
Glass Manufacturing	1,129	734	8,392	0	0	33
Mineral Processing	194,211	16,730	27,563	256	847	213
Kilns, Driers, Etc.	58,773	16,730	27,563	256	847	134
Material Handling	135,438	0	0	0	0	79

Metal Production	2,121	9,325	8,280	1,170	1,828	48
Metal Melting	1,764	3,474	6,745	1,170	1,828	22
Coking Operations	357	3,251	164	0	0	9
Metal Handling and Other Combustion	0	2,600	1,371	0	0	17
Chemical Processes	15,652	37,226	5,191	4,682	41,789	48
Commercial and Industrial Solvent Emissions	8,064	0	0	119,145	0	134
Agriculture, Timber, and Paper Processing	74,866	1,211	3,577	20,135	212,414	412
Agriculture Processing	16,223	0	546	1,190	0	54
Lumber Processing and Manufacturing	55,019	0	1,745	14,952	119,969	342
Paper Manufacturing	3,624	1,211	1,236	3,993	12,445	6
Miscellaneous	9,118	2,347	4,482	7,997	25,601	53
Totals	319,916	256,525	225,464	260,174	433,265	1,283

2.2.1 Electric Power Generation. The air pollution problems associated with electric power generation result primarily from combustion. Fuel handling and storage contribute an additional, smaller amount. The majority of the combustion-associated emissions come from steam electric plants because they are among the largest combustion devices made, burn the largest amounts of fuel and are operated at a high fraction of maximum load a high percentage of the time.

The emissions due to fuel handling are primarily fuel evaporation sources.

Table 2-IV shows the relative amount of the total of all source categories of each pollutant that results from electric power generation. These percentages represent emissions only from sources emitting 100 tons/year or more of each pollutant.

Table 2-IV. Percentage of Total Emissions of Each Pollutant Due to Electric Power Generation

Pollutant	% Of Total For Each Pollutant
Particulate	2.8
SO <sub>2</sub>	27.2
NOx	53.3
Hydrocarbons	7.2
CO	0.9

Steam-electric generating facilities are large combustion devices that use the hot combustion products to produce high pressure steam which is used to drive turbine generators. The emission problems associated with this type of device are due primarily to the combustion process. Most of the steam plants in California are fired with gas a large percent of the time. Because of this, for a large portion of the time the SO<sub>2</sub> emissions

are very low;  $\text{SO}_2$  and particulate emissions usually become substantial only when oil fuel or coal is burned. However, present trends indicate a much heavier dependence on oil because of increased natural gas curtailment; thus  $\text{SO}_2$  and particulate emissions will become larger than existing summaries.

In general, steam electric plants are among the best controlled and monitored devices. They tend to be designed in such a manner that they allow for very flexible operation; that is, there are numerous combustion variables that can be adjusted. Due to these factors, there are wide variations in what is considered to be safe and normal operation. The emission rates of some pollutants vary considerably with the operational mode, and as a result, emissions from a given device, at a given load, on a given fuel, can be quite variable.

The load at which these devices operate varies substantially and frequently. Whereas some combustion devices operate at a given load for days or weeks at a time, a typical steam boiler for a power plant operates at a given load for only hours at a time. Since emissions are a function of load (among other things), the result is that the emissions vary considerably with time.

In order to determine which devices could effectively use monitors, each category was examined. In some cases monitors would not be cost effective due to the lack of a singular emission point. In other cases the devices might have been in a remote location where pollution damage costs are low in comparison to the monitor costs. In the following tables, the representation "monitor can be used" means the device is large, has a singular emission source, and is amenable to installation of an extractive or in situ monitor.

Table 2-V shows which pollutants the devices in this category are likely to produce in substantial quantities and therefore what type of monitors would be required.



Table 2-V. Pollutant Types for Electric Power Generating Facilities

Device Type	Part	SO <sub>2</sub>	NOx	HC	CO	Number of Sources Emitting 100 tons/year or more of any one pollutant
Electrical Generation	0	0	0	0	0	125
Fuel handling and storage				0		5

0 Monitor can be used

2.2.2 Gas/Oil Producing Equipment. There are four types of functions considered in this category of device: combustion, compression and transportation, storage and handling, and miscellaneous devices. Combustion devices include refinery heaters and boilers, which burn oil, refinery gas, and natural gas. Most of the devices involved in compression and transportation are internal combustion engines which turn compressors and pumps; generally these devices are fueled by natural gas or petroleum storage vapors. Storage and handling emissions are related to evaporation of petroleum. Miscellaneous devices encompass flares, CO boilers, sulfur recovery units, etc.

Table 2-VI shows the relative amount of each pollutant that results from gas and oil producing operations; these percentages represent emissions only from sources emitting 100 tons/year or more of each pollutant

Table 2-VI. Percent of Total Emissions of Each Pollutant Due to Gas and Oil Production

Pollutant	% of Total for Each Pollutant
Particulate	1.6
SO <sub>2</sub>	38.7
NOx	16.7
Hydrocarbons	26.4
CO	31.9

Refinery heaters are used to heat oil for purposes of distillation, reforming, cracking, etc. in order to produce the desired petroleum products. Refinery boilers are used to produce process steam for various operations which include driving steam power equipment and providing heat in some refining processes.

These devices tend to be smaller than power plant boilers and considerably less well monitored and instrumented. Because of this, it is likely that the operating parameters for a given load and a given device can vary considerably. Another important variable is the fuel. Most combustion devices in refineries burn, in addition to oil, a mixture of natural gas and refinery gas. Refinery gas is a complex and variable mixture of fuels which are obtained from vapor recovery systems, vents, etc., plus some higher quality fuels such as hydrogen, propane, and butane.

Because of these factors, the emissions from these devices can vary considerably between seemingly identical devices, and can vary from hour to hour for a given device.

As can be seen from Table 2-VI, refinery combustion devices emit substantial percentages of all five major pollutants. In general, however, refinery combustion devices are not equipped with emission control devices (a notable exception is fluid catalytic cracking units, which will be discussed later).

Emissions due to the compression and transportation of gas and oil result primarily from internal combustion (IC) engines and fuel evaporation. Since most of the operating variables are locked-in by design, the emissions from a given IC engine are essentially related directly to load. The primary emissions from IC engines are NO<sub>x</sub> and CO. As in the case of refinery heaters and boilers, these engines are uncontrolled.

The main emission due to storage and handling is hydrocarbons from evaporation of fuel.

Emissions from miscellaneous devices consist of all five major pollutants. Since this category includes a variety of device types, it is difficult to make general statements regarding the source of emissions. However, among the major types of devices accounted for in this category are: sulfur recovery plants, which convert gaseous sulfur compounds to

molecular sulfur; and CO boilers, which burn the large amounts of CO which are generated during catalyst regeneration in a fluid catalytic cracking unit.

Table 2-VII shows which pollutant the devices in this category are likely to produce in substantial quantities and therefore, what type of monitors would be required.

Table 2-VII. Pollutant Types for Gas and Oil Producing Equipment

Device Type	Particulate	SO <sub>2</sub>	NOx	HC	CO	Number of sources emitting 100 tons/year or more of any given pollutant
Heaters and Boilers	O	O	O	O	O	64
Compression and Transportation			X	O	X	14
Storage and Handling				O		94
Miscellaneous	X	X	X	X	X	43

O Monitor can be used

X Monitor can be used dependent on specific device under consideration

2.2.3 Glass Producing Equipment. The primary emissions due to glass manufacturing are the result of glass melting (combustion). Table 2-VIII shows the relative amount of each pollutant that results from glass producing operations; these percentages represent emissions only from sources emitting 100 tons/year of each pollutant.

Table 2-VIII. Percent of Total Emissions of Each Pollutant Due to Glass Production

Pollutant	% of Total for Each Pollutant
Particulate	0.3
SO <sub>2</sub>	0.2
NOx	2.9
Hydrocarbons	0
CO	0

Most glass melting furnaces use the hot combustion products to heat the glass directly, that is, the flame impinges directly on the glass. As a result, in addition to the normal combustion pollutants, additional particulates are entrained in the exhaust gases.

Table 2-IX shows which pollutants this type of device is likely to produce in substantial quantities and therefore, what types of monitors would be required.

Table 2-IX. Pollutant Types for Glass Furnaces

Device Type	Particulate	SO <sub>2</sub>	NOx	HC	CO	Number of sources emitting 100 tons/year or more of any given pollutant
Glass Melting	0	0	0			33

0 Monitor can be used

2.2.4 Mineral Industry Equipment. The types of devices used by industries in this category include ceramic kilns, asphalt batch plants and cement kilns, and material handling systems for such materials as cement, aggregate, sand, etc. Table 2-X shows the relative amount of each pollutant that results from mineral industry operations; these percentages represent emissions only for sources emitting 100 tons/year or more of each pollutant.

Table 2-X. Percent of Total Emissions of Each Pollutant Due to Mineral Industries Operations

Pollutant	% of Total for Each Pollutant
Particulate	53.6
SO <sub>2</sub>	5.4
NOx	9.6
Hydrocarbons	0
CO	0

In many of the devices in this category, a finely divided mixture of solid materials is heated by direct contact with the combustion product gases. Because of this, the pollutants emitted are those expected from combustion devices. Additionally, some portion of the process material is usually entrained in the exhaust gas, resulting in a higher particulate loading. During loading and handling operations, particulate matter is generated in the form of dusts. Typical control devices include precipitators, bag houses, cyclones, etc. to control particulates. Successful

application of such control devices depends upon localization of the emissions such as through hoods or vents.

Table 2-XI shows which pollutants the devices in this category are likely to produce in substantial quantities and therefore what types of monitors are likely to be required.

Table 2-XI. Pollutant Types for Mineral Industry Devices

Device Type	Particulate	SO <sub>2</sub>	NOx	HC	CO	Number of sources emitting 100 tons/year or more of any given pollutant
Kilns, dryers, etc.	O	O	O	O	O	79
Material handling	X					134

O Monitor can be used

X Monitor can be used dependent on the nature of the specific device

2.2.5 Metal Producing Equipment. There are three types of devices included in this category: metal melting furnaces, coking ovens, and other combustion devices, which includes reheat ovens, mill ovens, and boilers.

Table 2-XII shows the relative amount of each pollutant that results from metal producing operations; these percentages represent emissions only from sources emitting 100 tons/year or more of each pollutant.

Table 2-XII. Percent of Total Emissions of Each Pollutant Due to Metal Production

Pollutant	% of Total for Each Pollutant
Particulate	0.7
SO <sub>2</sub>	3.6
NOx	3.7
Hydrocarbons	0.5
CO	0.4

Metal melting devices include open hearth furnaces, blast furnaces, etc. in which metals are refined or melted prior to casting. In most of these devices, the hot combustion products impinge directly on the metal

with the result that, in addition to the normal pollutants associated with combustion, additional particulates are produced. Therefore, many metal melting devices are equipped with particulate control devices. Since many of these processes involve the use of coke as a reducing agent, large amounts of CO are also generated.

Coking ovens involve heating coal to drive off volatile hydrocarbons and other materials. Although most of these volatile materials are used for fuel in the plant, some hydrocarbons are released over and above those generated in the combustion processes.

Other combustion processes involved with metal production include most of the devices used for heating metal for purposes of milling, forming, etc. The major pollutants from these devices result from the combustion process, but additional particulate emissions can occur due to rolling and milling operations.

Table 2-XIII shows which pollutants the devices in this category are likely to produce in substantial quantities and therefore, the types of monitors which would be required.

Table 2-XIII. Type of Pollutants for Mineral Industry Devices

Device Type	Particulate	SO <sub>2</sub>	NOx	HC	CO	Number of sources emitting 100 tons/ year or more of any given pollutant
Metal Melting Furnaces	0	0	0	0	0	22
Coking Operations	0	0	0	0	0	9
Other Combustion	0	0	0	0	0	17

0 Monitor can be used

2.2.6 Chemical Process Equipment. This category of devices includes a wide variety of different processes and devices which generate emissions from combustion processes, chemical reactors, and handling of various chemical processes.

Table 2-XIV shows the relative amount of each pollutant that results from chemical production and related processes; these percentages represent emissions only from sources emitting 100 tons/year or more of each pollutant.

Table 2-XIV. Percent of Total Emissions of Each Pollutant Due to Chemical Processing Equipment

Pollutant	% of Total For Each Pollutant
Particulate	4.9
SO <sub>2</sub>	14.5
NOx	2.3
Hydrocarbons	1.9
CO	9.6

Since this category includes a wide variety of combustion and process devices, it is not possible to give a general description of the equipment included in this category. Likewise, the emissions from any individual device depend on the details of the process. However, as can be seen from the table below, all five types of emissions are emitted from the aggregate of these devices.

Table 2-XV shows which pollutants the devices in this category are likely to produce in substantial quantities and therefore, which pollutants need to be monitored.

Table 2-XV. Type of Pollutants for Chemical Process Equipment.

Device Type	Particulate	SO <sub>2</sub>	NOx	HC	CO	Number of sources emitting 100 tons/year or more of any given pollutant
Process Equipment	X	X	X	X	X	48

X Monitor can be used dependent on details of the process under consideration

2.2.7 Commercial and Industrial Solvent Emissions. Emission sources in this category include such things as dry cleaning facilities, printing facilities, coating and painting facilities, etc. Although the primary emissions from these devices are hydrocarbons, particulate emissions accompany solvent emissions in some cases.

Table 2-XVI shows the relative amount of each pollutant that results from commercial and industrial solvent emitting sources; these percentages represent emissions only from sources emitting 100 tons/year or more of each pollutant.

Table 2-XVI. Percent of Total Emissions of Each Pollutant  
Due to Commercial and Industrial Solvent Emissions

Pollutant	% of Total for Each Pollutant
Particulate	2.5
SO <sub>2</sub>	0
NOx	0
Hydrocarbons	47.7
CO	0

All of the devices in this category produce hydrocarbons due to evaporation of solvents. In printing facilities, for example, the solvents used in inks are released during drying. Emissions of this type can be controlled by the use of afterburners and solvent recovery systems. Afterburners remove hydrocarbons from gas streams by passing them through a combustion device which combusts the solvents. In some of these operations (coating and painting facilities in particular) particulates are also generated. Solvent recovery systems, as the name implies, recover the solvents in some usable form rather than destroying them.

Table 2-XVII shows which pollutants the devices in this category are likely to produce in substantial quantities and therefore, what type of monitors would be required.



Table 2-XVII. Type of Pollutants for Industrial and Commercial Solvent Emissions Sources

Device Type	Particulate	SO <sub>2</sub>	NOx	HC	CO	Number of sources emitting 100 tons/year or more of any given pollutant
Commercial/Industrial Solvent Emissions	X			O		132

O Monitor can be used

X Monitor can be used dependent on details of the process

2.2.8 Agricultural and Timber Operations. Emission sources in this category are those involved with drying, processing, and handling of agricultural products; sawing, sanding, and working of timber products; and paper manufacturing operations.

Table 2-XVIII shows the relative amount of each pollutant that results from these types of operations; these percentages represent emissions only from sources emitting 100 tons/year or more of each pollutant.

Table 2-XVIII. Percent of Total Emissions of Each Pollutant Due to Agricultural and Timber Operations

Pollutant	% of Total for Each Pollutant
Particulate	23.4
SO <sub>2</sub>	0.5
NOx	1.6
Hydrocarbons	8.0
CO	49.0

Although this category covers a large number of different types of sources, the predominant areas are:

Agricultural Processing - Grain loading and product drying pre-dominate. Grain loading operations produce mainly particulate matter. Unless the loading procedures take place under a hood

of some type, there is no point at which a monitor can be installed since the emissions are somewhat diversified. Agricultural product drying processes and rice hull burning, although combustion processes, do not emit SO<sub>2</sub> or CO in such amounts that any one unit emits 100 tons/year or more of either. In addition to the combustion-related emissions, additional particulates and hydrocarbons are emitted from the products themselves.

Timber Operations - A substantial source in this category is Teepee burners in which waste wood and sawdust are burned. These devices tend to produce large amounts of CO and lesser amounts of particulates and hydrocarbons.

Paper Manufacture - The various operations involved in paper manufacturing, produce substantial quantities of all five major pollutants.

Table 2-XIX shows which pollutants the devices in this category are likely to produce in substantial quantities and therefore, what type of monitors would be required.

Table 2-XIX. Type of Pollutants for Agricultural, Timber, and Paper Manufacturing

Device Type	Particulates	SO <sub>2</sub>	NOx	HC	CO	Number of sources emitting 100 tons/year or more of any given pollutant
Agricultural Processing	X		X	X		54
Lumber Processing and Manufacturing	O		X	X	X	342
Paper Manufacturing	O	O	O	O	O	428

O Monitor can be used

X Monitor can be used dependent on the details of the process under consideration

2.2.9 Miscellaneous Sources. This category includes all emission sources that are not readily classifiable in any other category. Among the largest contributors to the emissions from this category come from burning at trash dumps. Table 2-XX shows the relative amount of each pollutant that results from these types of operations; these percentages represent emissions only from sources emitting 100 tons/year or more of each pollutant.

Table 2-XX. Percent of Total Emissions of Each Pollutant Due to Miscellaneous Sources

Pollutant	% of Total for Each Pollutant
Particulate	2.9
SO <sub>2</sub>	0.9
NOx	2.0
Hydrocarbons	3.2
CO	5.9

Since a major portion of the emissions are a result of trash burning, which is an area type emission (i.e., there is no stack or highly localized combustion zone), it is not possible to use a stack type monitor. The monitoring requirements for the remaining miscellaneous devices depend primarily on the particular process involved.

Table 2-XXI shows which pollutants the devices in this category are likely to produce in substantial quantities and therefore what type of monitors would be required.

Table 2-XXI. Type of Pollutants for Miscellaneous Devices

Device Type	Particulate	SO <sub>2</sub>	NOx	HC	CO	Number of sources emitting 100 tons/year or more of any given pollutant
Miscellaneous	X	X	X	X	X	53

X Monitor can be used depending on the detailed characteristics of the sources

### 2.3 Air Pollution Damage Estimates by Source Category.

The relative advantages in the application of continuous monitors to the source categories of Table 2-III can be illustrated by using the method described by Babcock and Nagda.<sup>(10)</sup> Severity factors are assigned to different pollutants relative to carbon monoxide. Table 2-XXII gives the factors derived by those authors:

Table 2-XXII. Severity Factors For Specific Pollutants  
(After Reference 10)

<u>Pollutant</u>	<u>Severity Factor</u>
Particulate Matter	52
Sulfur oxides	29
Nitrogen oxides	24
Hydrocarbons	10
Carbon monoxide	1

The total air pollution damage costs can be estimated by multiplying the emissions of a given pollutant by its severity factor by the damage cost per severity ton. Barrett and Waddell<sup>(11)</sup> have arrived at an average cost figure of \$4.63/severity ton for residential property and health damage.

On this basis Table 2-XXIII summarizes the estimated cost of air pollution residential and health damage resulting from each source category. Because of the heavy weighting factor for particulates, mineral processing devices have the largest estimated damage cost, \$52,000,000 per year, versus the next largest, \$27,000,000 per year, for gas and oil operations.

A measure of the effectiveness of monitoring is the damage cost per device. Power plants, mineral processing, and chemical processes all have averages of about \$200,000 air pollution damage per device. Thus, a \$20,000 continuous monitor would represent only 10% of the average annual damage costs. On this basis, the use of the monitor to ensure emission reductions of only 10% would result in meeting the monitor cost after a year. At the other extreme, glass manufacturing, agriculture, timber and paper processing, metal production and commercial and industrial solvents have averages of \$40,000-\$60,000 per device. The monitor costs could comprise as much as 30-50% of the estimated annual damage resulting from the operation of the individual source.

Table 2-XXIII. Air Pollution Damage Costs by Source Category

	Severity Tonnage Per Year					Annual Estimated Total Damage Cost (\$ x 10 <sup>6</sup> )	Annual Estimated Damage Cost Per Device (\$)
	Particulate	SO <sub>2</sub>	NOx	HC	CO		
Power Plant Operations	471,000	2,022,000	2,885,000	181,200	4,017	25.8	199,000
Gas and Oil Operations	296,000	3,458,000	1,146,000	787,000	147,000	27.0	127,000
Glass Manu.	59,000	21,000	201,000	0	0	1.3	39,000
Mineral Processing	10,100,000	485,000	661,500	2,600	850	52.0	244,000
Metal Production	110,300	270,000	199,000	11,700	1,800	2.7	57,000
Chemical Processes	814,000	1,080,000	125,000	46,800	41,800	9.8	203,000
Commercial & Industrial Solvents	419,000	0	0	1,191,000	0	7.5	56,000
Agri., Timber and Paper Processing	3,890,000	35,000	85,900	201,000	212,000	20.5	50,000
Misc.	474,000	68,000	108,000	80,000	25,600	3.5	66,000

### 3.0 CONTINUOUS MONITOR SYSTEMS

To determine the feasibility of continuous monitoring for each source classification, a survey was made of the sources emitting greater than 100 tons/year of any pollutant. The major source classifications and the species emitted for each were then tabulated (cf. Section 2). After classifying each source and the pollutants emitted, it was determined that the systems of greatest interest to this study were those with the capability to measure NOx, SO<sub>2</sub>, hydrocarbons, CO, particulate, and opacity. Information was then gathered on specific systems for measuring these pollutants.

#### 3.1 Types of Systems

Currently available systems are generally divided into two classes: extractive and in situ. Extractive systems generally consist of the following elements: sample acquisition and conditioning, analytical instrumentation, calibration and data recording. With in situ systems, the analytical instrument is mounted on the stack or process stream duct. The photometric and spectroscopic instruments used as in situ devices consist of a light source on one side of the duct and a detector on the other so that the instrument sees the full width of the duct. Calibration is accomplished with calibration cells or optical filters. Data recording capability is identical with extractive systems.

The gaseous pollutants of interest are currently measured using either the extractive or in situ technique. Opacity is only measured using in situ instruments. Particulate is generally measured using extractive techniques although in situ instruments are in the development stage. Particulate may be correlated to opacity under specific conditions.<sup>(8)</sup>

#### 3.2 System Description

The following paragraphs describe the characteristics of both the extractive and in situ measurement systems.

3.2.1 Extractive Systems. The extractive system generally consists of a sample acquisition and conditioning system, analytical instrumentation, calibration and data recording.

## Sample Acquisition

Sample acquisition is usually accomplished with one or more probes inserted into the stack or process stream duct. Multiple probes may be required to ensure that a representative sample of the gas stream is obtained. In cases where the process stream contains particulate, a filter may be required to protect the sampling system and analytical instrumentation. The most common method to accomplish this is to install a filter on the inlet to the probe. Figure 1 is a drawing of such a probe. The filter elements can be made of porous stainless steel, silicon carbide, or stainless steel mesh with pore sizes varying from 1 to 50 microns. As the sample is pulled through the element, particles collect on the filter. This eventually causes a high pressure drop across the element, causing sample flow to stop to the analyzer. This can be alleviated by installing a shield around the filter element to prevent direct impact of particles on the filter element. Reverse flow through the filter element can be periodically established with compressed air, cleaning the filter. Some particles may still remain in the filter and eventually the filter may require replacing. The frequency of replacement is dependent upon the particle loading of the process stream.

An alternative approach to the filter removes solids from the gas stream by "reflux" filtration. Externally the probe has the appearance of an ordinary open tube probe. In operation, a large volume of gas is withdrawn from the stack and a large fraction is forced back into the stack at high velocity. The effect of the return stream is to shield the end of the tube from particulate material, allowing only the gas phase to enter. Figure 2 shows this type of probe (after Ref. 13).

## Sample Conditioning

The conditioning system which is required to deliver the sample to the analyzers in the proper state for analysis may be located at the sample point or some distance away for convenience in installation and maintenance. Due to the reactive nature of several compounds normally found in combustion gases and process streams, the sample lines and components should be stainless steel, high temperature fluorocarbon or other suitably inert material. The sample transmission line can be either heated or unheated, depending upon the constituents to be measured and the system design. Condensate must be avoided to eliminate flooding of

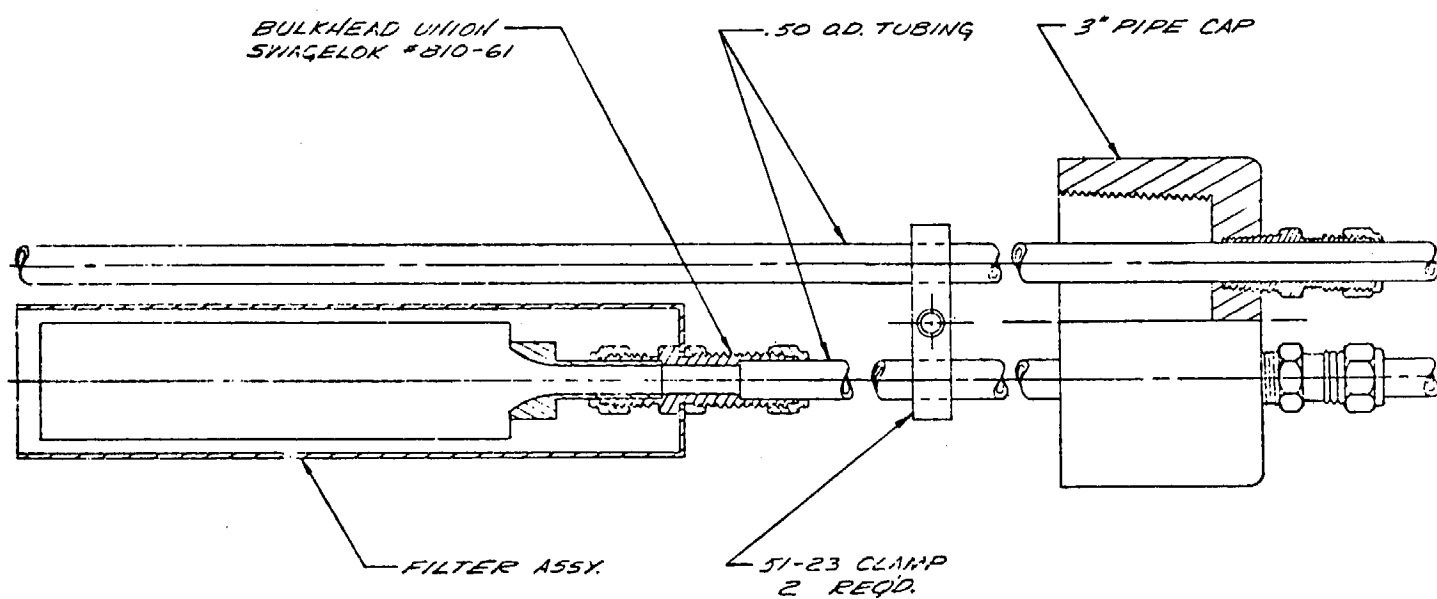


Figure 1. Filtered Probe for Extractive System.



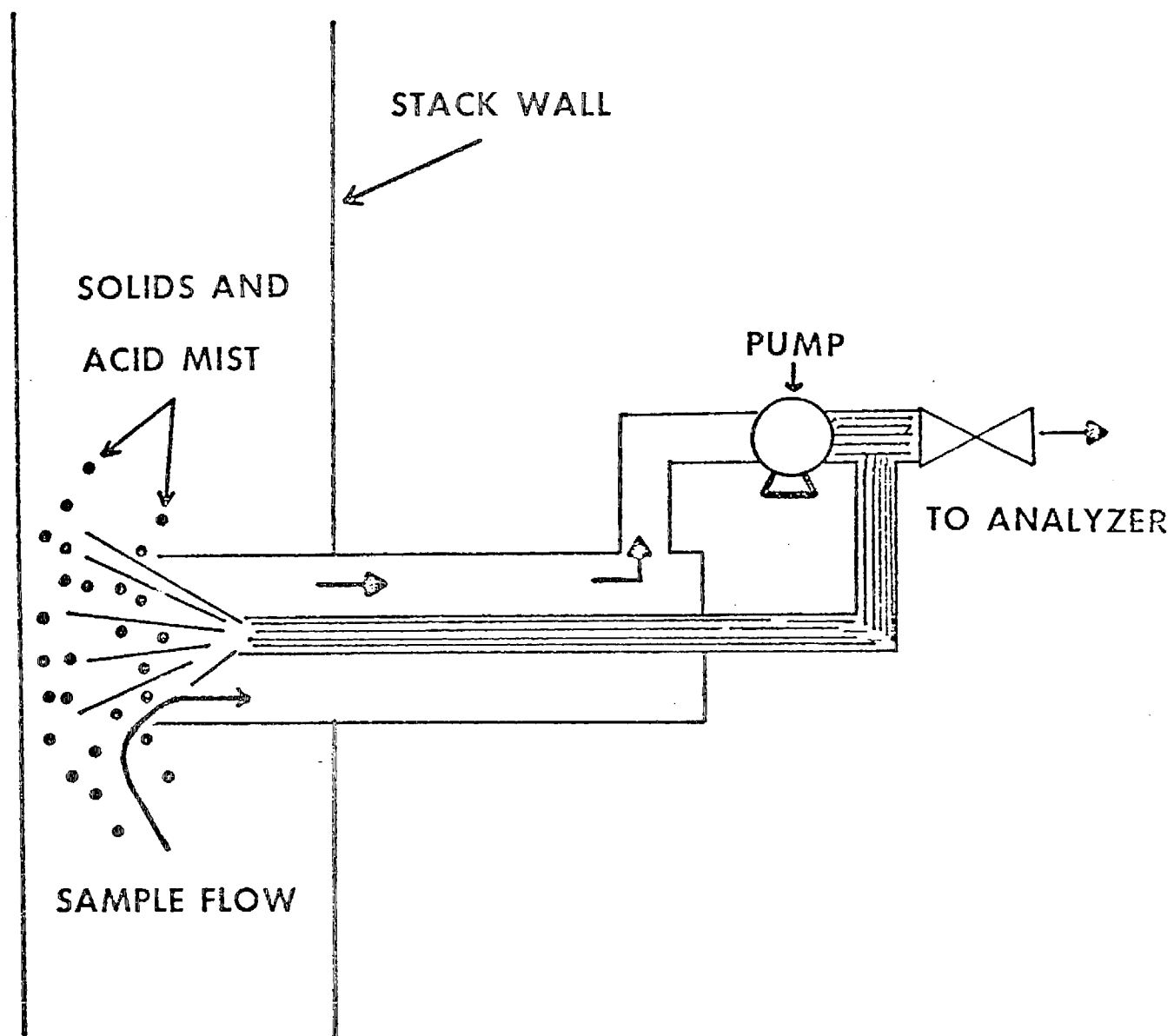


Figure 2. Reflux Probe for Extractive System (After Ref. 13).

components, loss of gaseous constituents due to solubility in liquid and severe corrosion where  $\text{SO}_3$  is present. Both steam and electrical tracing are currently used for heating the lines with electrical heating the more common of the two. The sampling system usually has an additional filter to remove any particulate which may have entered the system. This filter protects the pumps and analyzers from contamination. Motive power for the sample is usually provided by a positive displacement pump. The common types in use today are diaphragm and bellows pumps with inert internal parts or inert coating of internal parts.

Condensate removal, where required, is usually accomplished with a refrigerated condenser with stainless steel or Teflon internal parts. Usually mechanical refrigeration drying temperatures range between 35° to 40°F to prevent ice formation in the cold trap, which would require periodic defrosting. Condensate removal after the heat exchangers can be effected by various types of mechanical drain systems or traps. Corrosion resistance is obtained with stainless steel or an inert plastic. A good design provides minimum contact between the sample and the liquid condensate and minimizes droplet carry-over. Traps are available with either manual or automatic drain valves.

A permeable membrane dryer can also be used to remove moisture from sample streams. This type of dryer uses a permeable membrane as a desiccant and a dry gas for continuous regeneration. The dryer is designed as a tube-in-shell configuration where the sample enters one side of the membrane and the dry purge gas flows on the other side. Its advantage is that the sample is dried with no loss of  $\text{SO}_2$ ,  $\text{NO}$ , or  $\text{NO}_2$ , and no moving parts are involved. Figure 3 (after reference 14) gives a schematic of this type of dryer.

Since all continuous analyzers used in these applications suffer from interferences of some sort, sample pretreatment such as filtering and drying is essential prior to analysis. As a result, the importance of proper conditioning by tailoring the pretreatment system to the various analyzer needs without compromising the validity of the sample cannot be underestimated. Photographs of typical installations are shown in Figures 4 and 5. Figure 6 is a generalized flow schematic of a typical system.

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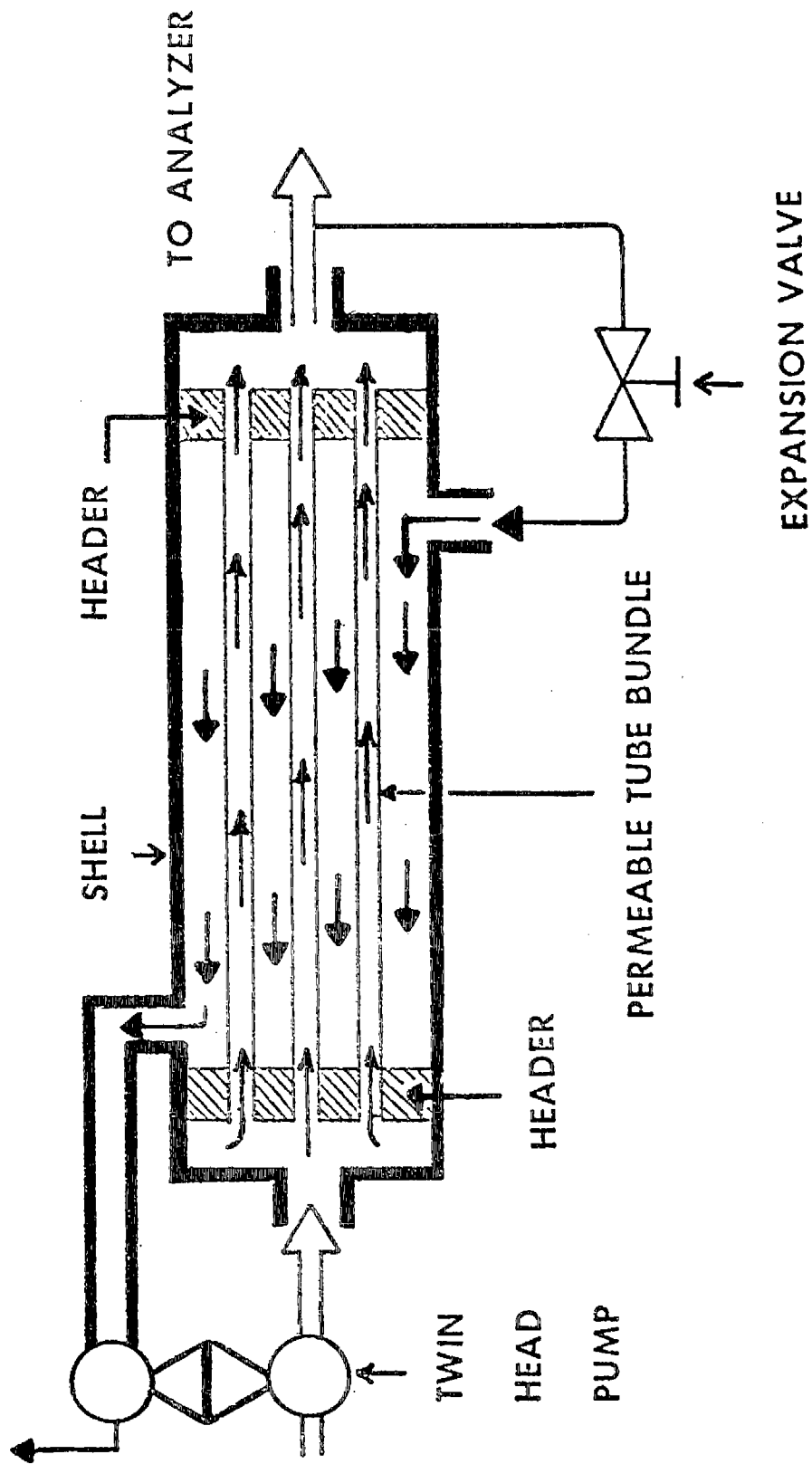
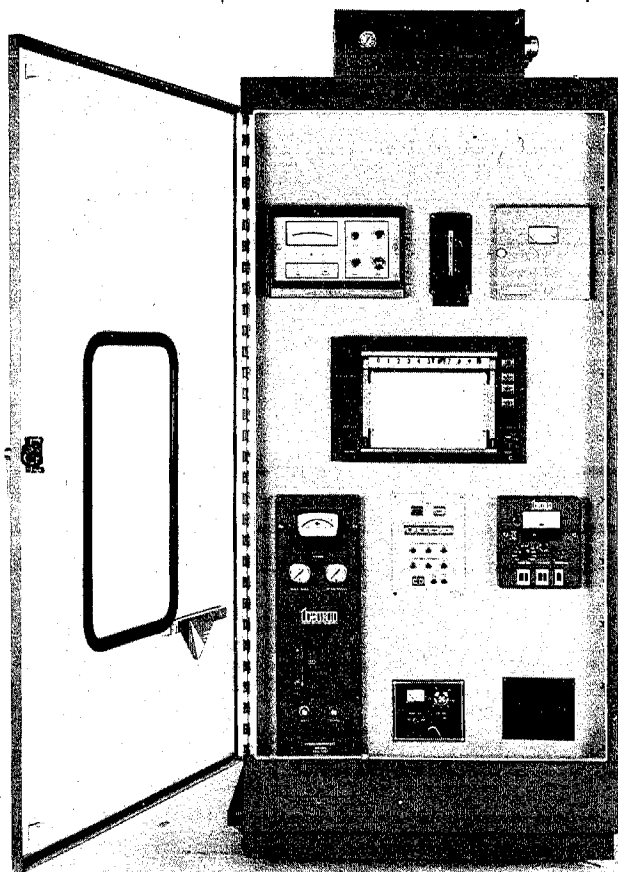
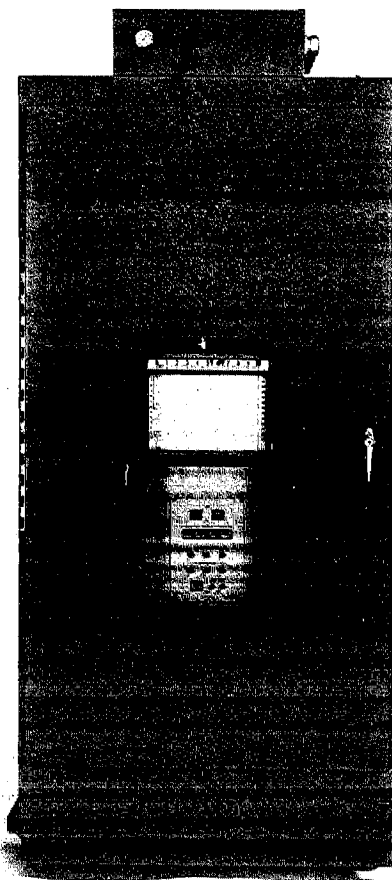


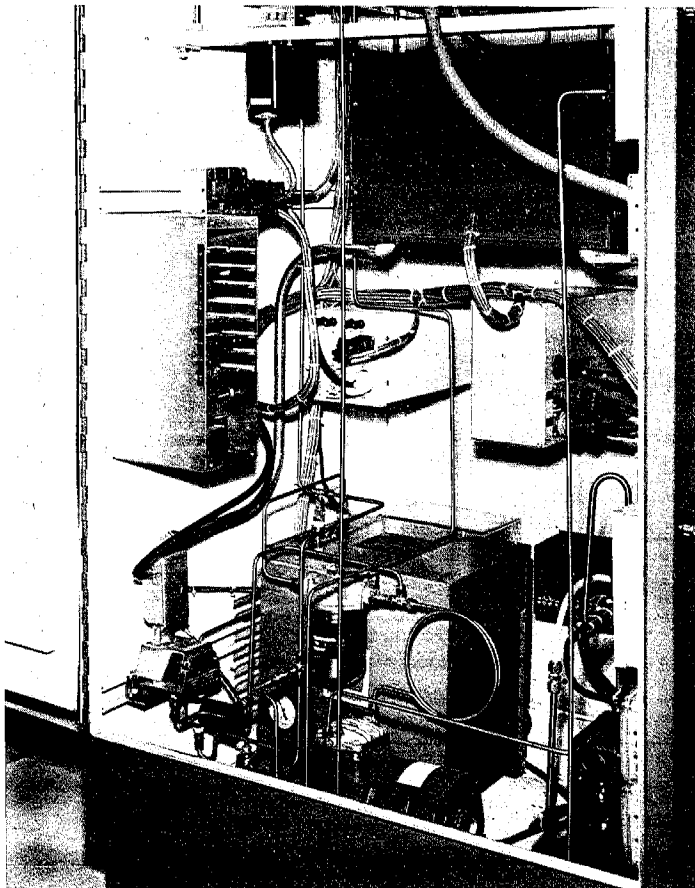
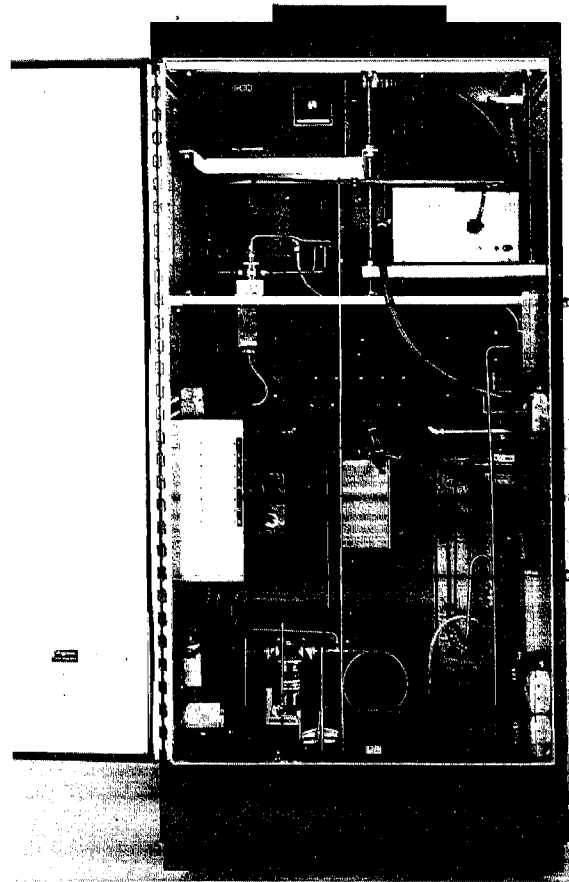
Figure 3. Permeable Membrane Dryer.

Continuous Monitor weatherproof housing. Window provides view of strip chart recorder, system visual alarms and systems operational mode.



Continuous Monitor instrument panel showing NO<sub>x</sub>, CO, and O<sub>2</sub> analyzers, strip chart recorder, automatic control panel, heated line controller, and stack selector control for monitoring 4 stacks in succession.

View of Continuous Monitor through rear access doors showing sample handling components such as pumps, filters, refrigerated condenser and controllers.



Closeup of Continuous Monitor sample handling components. Printed circuit boards providing automatic calibration and correction capability are shown mounted in card rack on side wall.

Figure 5.

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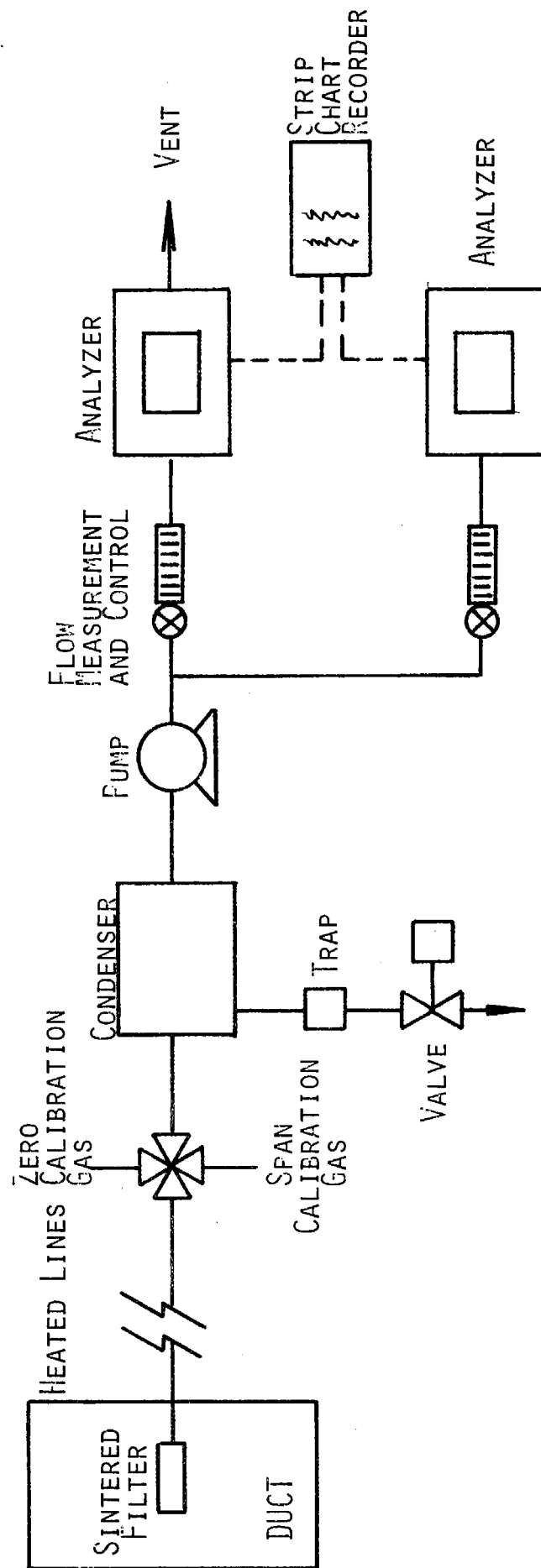


FIGURE 6. SCHEMATIC OF EXTRACTIVE CONTINUOUS MONITOR

Analytical instruments are currently available for measuring gaseous emissions using non-dispersive infrared, chemiluminescent, UV photometric, and electrochemical techniques<sup>(16)</sup>.

Non-dispersive infrared analyzers are currently being used to measure NO, CO, and SO<sub>2</sub> concentrations. These instruments measure the differential in infrared energy absorbed from monochromatic light beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wavelength absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale from 0 to 100 and is then related to the concentration of the specie of interest by calibration curves supplied with the instrument.

Another common method of detection of oxides of nitrogen is with the chemiluminescent technique. The basis of this technique is the chemiluminescent reaction of NO and O<sub>3</sub> to form NO<sub>2</sub>. Light emission results when electronically excited NO<sub>2</sub> molecules revert to their ground state. This resulting chemiluminescence is monitored through an optical filter by a high sensitivity photomultiplier, the output of which is linearly proportional to the NO concentration.

The basic analyzer is sensitive only to NO molecules. To measure NOx (i.e., NO + NO<sub>2</sub>), the NO<sub>2</sub> is first converted to NO. This is accomplished by a converter which is included with the analyzer. The conversion occurs as the gas passes through a thermally insulated, resistance heated, stainless steel coil. With the application of heat in the presence of the stainless steel catalyst, NO<sub>2</sub> molecules in the sample are reduced to NO molecules, and the analyzer now reads NOx. NO<sub>2</sub> is obtained by the difference in readings obtained with and without the converter in operation.

The UV photometric technique is used in determining gaseous concentrations of NO<sub>2</sub> and SO<sub>2</sub>. This type of analyzer measures the difference in absorption of two distinct wave lengths (ultraviolet) by the sample. The radiation from a selected light source passes through the sample and then into the photometer unit where the radiation is split by a semi-transparent mirror into two beams. One beam is directed to a

phototube through a filter which removes all wave lengths except the "measuring" wave length, which is strongly absorbed by the constituent in the sample. A second beam falls on a reference phototube, after passing through an optical filter which transmits only the "reference" wave length. The latter is absorbed only weakly, or not at all, by the constituent in the sample cell. The phototubes translate these intensities to proportional electric currents in the amplifier. In the amplifier, full correction is made for the logarithmic relationships between the ratio of the intensities and concentration or thickness (in accordance with Beer's law). The output is therefore linearly proportional, at all times, to the concentration and thickness of the sample.

Electrochemical transducers are also currently used to measure NO<sub>x</sub>, SO<sub>2</sub>, and CO. The electrochemical analyzers are polarographic instruments of the membrane type. The gas being analyzed permeates the membrane and is immediately oxidized at the sense electrode. The electrical signal from the transducer is directly proportional to the concentration of the gas being monitored. Response is linear over the range covered. The transducer is designed to operate at atmospheric pressure.

#### Calibration

Calibration determines the relationship between the response of an instrument or analytical technique and known values of the pollutant being measured. Calibration of extractive systems usually involves the introduction of gas samples of known composition into the system for the purpose of producing a calibration curve or adjusting the analyzer response to a predetermined value. The conditions are made to duplicate the concentrations expected in the streams to be tested.

#### Summary

By careful attention to the potential problems, an extractive continuous monitor system offers the following advantages:

- o No limitation exists on stack, duct, or process line size, temperature, or location. The monitor can receive samples from any convenient and appropriate site.
- o Dry basis analyses are provided directly, with an appropriate sample conditioning system.



- o Multiple units can be monitored by time sharing
- o Spatial information within the duct can be obtained to derive additional benefits regarding efficiency and operating problems.
- o Direct, automatic calibration is possible

The major potential problems to be considered are:

- o Probes and filters are prone to plugging from high particulate or reactive streams. Periodic maintenance and/or purging systems may be required.
- o Corrosion of system components may be a problem in reactive streams.
- o Response time is greater than in situ systems.
- o Regular maintenance of several mechanical and electronic systems is required.

3.2.2 In Situ Monitoring Systems. Typical in situ monitoring systems for NO<sub>x</sub>, SO<sub>2</sub>, CO, and HC consist of a light source, receiver, mounting assembly, and recording instrument. Most in situ systems are based on some form of absorption spectroscopy measuring in the ultraviolet, near-infrared, and/or visible parts of the optical spectrum. In addition, opacity measurement is done using in situ devices which are discussed in the next section.

Spectroscopy is based on the principle that when light passes through a material, certain wavelengths are absorbed or reduced in intensity. The wavelengths where the energy is reduced are specific to the chemical composition of the absorbing media. The concentration of the material in the light path is a unique function of the intensity of these selected absorption lines.

Examples of the types of in situ absorption spectrometers commonly used are a broad band system, second-derivative system, and a correlation system.

The operating principle of the in stack correlation spectrometer is as follows: sulfur dioxide has characteristic multiple absorption lines, or a "fingerprint" in the ultraviolet region of the spectrum. By physically comparing the absorption spectrum of the gas in the flue with a photographic reproduction of the characteristic SO<sub>2</sub> absorption spectrum, the instrument is capable of producing an electrical signal proportional to the sulfur dioxide concentration in parts per million by volume.

Wide band absorption due to other gases or smoke is registered as an increase in the average light level reaching the photomultiplier tube (PMT). This is balanced out by comparing with a fixed DC reference and changing the gain on the PMT until a null is achieved. The effect is to compensate the AC signal representing the amplitude of the SO<sub>2</sub> absorption spectra for changes due to smoke or other absorbing materials. Output of the monitor is proportional to the concentration.

Second-derivative spectroscopy senses narrow band absorption. In essence a second-derivative spectrometer measures the change in curvature with respect to intensity. Second-derivative bands occur in the region of sharp energy absorption by molecules. The second-derivative peaks serve a dual role: (1) their wavelength locations identify the compound of particular interest, and (2) the peak heights are a linear function of concentration and are utilized for quantitative measurements. This analyzer is a tuned derivative spectrometer in which the wavelength has been set to the maximum of a second-derivative peak. The height of this peak is continuously monitored, and it is a measure of the gas concentration present in the stream. The linearity of the instrument extends from parts-per-billion to pure gas.

For a broad band system, the source emits polychromatic radiation that is collimated in multiple beams, sent through the window, and across the gas to be measured. A single beam from the source is used for each spectral region. The polychromatic radiation is received through the window and focused onto the entrance slit of the detection module.

A specially designed forced-air draft system is used to maintain relative cleanliness of each window and to define the optical path length.

The detection module separates the beam into two sets of component wavelengths which are selected to be the optimum choice for the measured absorbing gas and the adjacent background (non-absorbing) signals.

Both the absorption wavelengths and the background wavelengths are alternately chopped and then measured by one detector.

The electronics module ratios the signal from the detector. This signal is proportional to the mass of the gas present in the optical path length. By knowing the absorption coefficient of the gas and the path length, the concentration can be determined. The mass reading of the gas can then be expressed as parts per million.

The ratioed signals are then simultaneously amplified and transmitted to the continuous chart recorder. The typical calibration of in situ absorption spectroscopy analyzers is generally accomplished in one of two ways. The more common of the two is by using sample cells of known gas constituent concentrations. Following is a typical calibration sequence using this method.

This calibration involves setting the zero control, as well as the full scale span adjust, and finally includes a determination of the shape of the entire curve.

When a calibration check is made under operating conditions, the analyzer is reading some gas concentration. Thus the zero level must be checked by bypassing the stack gas. A separate light source is inserted into the analyzer module. The zero level can then be adjusted. Next, the full scale span setting is checked by inserting the proper amount of calibrating gas into the light beam. Since absorption of radiation is directly proportional to the number of molecules in the light beam, 10 ft of stack sampling path length containing 500 ppm of NO can be simulated by using a higher concentration in a shorter path.

Sealed cells containing the concentrations of gases desired are prepared, back-filled with nitrogen or air to bring the total pressure in the cell to atmospheric pressure, and then placed into the light beam for instrument calibration.

With both zero and full scale properly set, intermediate points, typically 20%, 40%, 60%, and 80% of full scale, are now checked by inserting the proper sealed cell with that equivalent gas concentration. The proper alignment of the analyzer is now verified.

The second technique is similar, only instead of using gas cells, optical filters are used.

### Summary

The advantages of in situ systems are generally related to the fact that a gas sample is not withdrawn for analysis:

- o The problems of sample extraction, transport, and conditioning are eliminated.
- o In the case of stack-mounted systems, the cost and complication of keeping gas samples above the dew point through long sample lines has been avoided.
- o An individual unit is usually less expensive than an extractive system.
- o High response times are possible.

The major potential problems to be considered are:

- o The location of the system is extremely important in order to insure a representative sample. Flow and/or concentration variations over the unit operating range must be defined in order to accurately locate the system.
- o Limitations for the location of in situ monitors are presented by the size of the duct, duct pressure changes, and duct flow rates which are not important for extractive systems.
- o In order to protect the "eye" of the analyzer from dirt and aerosols, filtered ambient air must be continuously blown in front of the sensor into the process stream.
- o Temperature compensation and alignment must be carefully provided where variations in process conditions occur.
- o Due to the single path composition average, the in situ system does not have the capability for measuring and defining the spatial distribution of gases within the stream.
- o If stack flow rates vary significantly, the penetration of ambient air (i.e. the air used to keep the window clean) into the stack may introduce some error. The significance of the error would, of course, be increased as the size of the stack decreases.
- o Each source requires its own monitor.

3.2.3 Opacity. Only in situ systems are available to measure the visible emissions opacity of the stack gases. The transmittance of a gas is defined as the fraction of radiant energy (in this case, light) which passes through a energy absorbing layer, the gas in the smokestack or duct. Within this same context, opacity can be defined as the ability of the gas to obstruct the transmission of light as a result of scattering and absorption by the particles. As the transmittance of a gas decreases, its opacity increases according to the amount and type of particulate matter entrained in the gas. The opacity of a gas is then determined by measuring the amount of light from a source of known intensity which passes through the gas. The opacity monitors generally consist of a light source, a detector, and electronic circuitry for providing a signal proportional to stack opacity.

The measuring beam of these transmissometers is projected across the entire diameter or width of the smoke channel to a detector, or in some cases, a retroreflector. The systems are insensitive to ambient light since they respond only to light chopped at one frequency. The light source can be either an incandescent lamp or a laser source. Opacity transmissometers, as with all in situ monitors, must have optical surfaces protected from the gases which are being measured. Once again this is generally accomplished with an air curtain furnished by an integral blower or compressed air. Output from the instrument is transmitted to the control room where an indication of opacity or transmittance is displayed.

Since the absorption and/or scattering of light radiation by a particle depends upon the optical and geometrical properties of the particle, light-transmission measurement alone does not generally provide sufficient data for determining the particulate mass concentration in the aerosol. In order to accurately measure the mass concentration of an aerosol by light-transmission techniques, the density, refractive index, and the shape and size distribution of the particles must remain constant. In actual practice, the relationship between mass concentration and light transmission must be established by calibration.

Calibration in dust loading is valid only as long as the particle size distribution and other particulate properties do not change significantly. In order to establish the accuracy of a transmissometer over a range of emission rates and process conditions, a large number of calibration points (at least 12 to 15) must be obtained, and the regression line and confidence limits must be statistically determined.

#### 3.2.4 Particulate Matter

The continuous measurement of particulate matter in a stack or process stream duct is the least developed of all the measurements of interest to this study. A number of measurement techniques have been evaluated and the beta radiation attenuation technique defined as the most promising. These instruments measure the concentration of particulates through the use of  $\beta$ -radiation absorption characteristics of collected particulate matter. The transmission of low energy  $\beta$ -radiation depends almost exclusively on the mass per unit area of the absorber. The maximum energy of the  $\beta$ -radiation and is independent of the chemical composition or the physical properties of the absorbing matter.

The particulate material is collected from a measured volume of stack gas on a fiberglass filter tape. Using a Carbon-14  $\beta$ -radiation source and a detector, the filter tape is radiometrically measured before and after sample collection. The ratio of the two radiation count rates is used to determine the concentration of the collected particulates. The sample volume is determined by regulating the sampling period and the gas flow rate. Throughout the sampling period, the gas flow rate is held constant and is continuously indicated. As a result, the weight of particulate per unit volume is obtained.

Particulate mass monitors require an extractive sample system to deliver the particulate to the analyzer and therefore require the same considerations in design as do extractive gaseous systems.

### 3.3 Current Systems Available

In order to determine the availability of systems to continuously monitor various source classifications, information regarding the availability of monitors was required. Information on system characteristics was solicited from major manufacturers for this specific purpose. Requests for information were sent to 14 manufacturers of monitoring systems. The information requested included data on system performance, operational requirements, special features, and approximate cost. A listing of the organizations contacted, a summary of the systems they have available, and a sample questionnaire, together with a definition of terms in the questionnaire, are included in the Appendix.

The results indicate that the application of continuous monitoring systems for measuring gaseous pollutant emissions has been feasible for several years. This judgment is based on the field-demonstrated ability of currently available NO<sub>x</sub>, SO<sub>2</sub>, CO, HC, and opacity monitoring systems (both extractive and in situ) to meet the proposed EPA performance specification (Ref. 3) for NO<sub>x</sub>, SO<sub>2</sub>, and opacity systems summarized below:

Table 3-I. Performance Specifications (Applied to Gaseous Measurements)

<u>Parameter</u>	<u>Specification</u>
1. Accuracy*	<20% of reference mean value
2. Calibration error*	< 5% of each (50%, 90%) calibration gas mixture value
3. Zero drift (3 hours)*	< 2% of emission standard
4. Zero drift (24 hours)*	< 4% of emission standard
5. Calibration drift (2 hours)*	< 2% of emission standard
6. Calibration drift (24 hours)*	< 5% of emission standard
7. Response time	15 minutes maximum
8. Operational period	168 hours minimum

\*Expressed as sum of absolute mean value plus 95% confidence interval of a series of tests

Table 3-II. Performance Specifications (Applied to Opacity Measurements)

<u>Parameter</u>	<u>Specification</u>
1. Calibration error	$\leq 10\%$ of test filter value*
2. Zero drift (24 hr)	$\leq 10\%$ of emission standard*
3. Calibration drift (24 hr)	$\leq 10\%$ of emission standard*
4. Response time	10 seconds maximum
5. Operational period	168 hours minimum

\*Expressed as sum of absolute mean value plus 95% confidence interval of a series of tests

The technology for continuous measurement of particulate matter (in terms of weight) has not yet been developed to the same extent that gaseous measurement systems have. As a result, there are not sufficient current quantitative standards by which relative performance can be judged.

Again, the systems of interest were those with the capability to measure the following emissions: NO<sub>x</sub>, SO<sub>2</sub>, SO<sub>2</sub>, HC, CO, particulate, and opacity. The study was limited to these five individual and one combined classifications since it was found that these systems would monitor about 90% of the sources in the state which emit greater than 100 tons/year of any of the pollutants considered. The data which were received were summarized and tabulated in Tables 3-III through 3-IX.

The data presented under System Performance shows all the systems to be well within the proposed EPA performance specifications. The quoted high system accuracies are surprising however, since the variability within the reference method itself against which accuracy is measured (i.e., PSDA for NO<sub>x</sub>) probably accounts for the rather wide EPA accuracy specifications of  $\leq 20\%$  and does not seem to be reflected in most of the manufacturer's data.

Although data was requested on system maintenance (see Operational Requirements in tables), very little information was made available which would allow an estimate of the manpower and cost required for maintenance, repair, and expendables. The limited data which was provided, however, allowed an estimate to be made that very roughly from 0.5 to 4% of the initial



Table 3-III

## SOURCE MONITORING SYSTEMS FOR NOX

1. Mfg. Model:	Dupont Model 461	Beckman Model 951 and Reflux Sampling Module	Environmental Data Corp.	MSA LIRA Model 303 or 202	Dyna Sciences P10IR
2. Principle of Operation:	VIS- Photometric	Chemiluminescent	In-situ absorption Spectroscopy	NDIR	Electro-Chemical
3. Method of Operation:	Intermittent 2 min. cycle	Continuous	Continuous Direct Viewing Industrial Gas Analyzer	Continuous	Continuous
4. System Performance					
a. Range:	5 ppm to 100%	0-10 ppm to 0-10,000 ppm	0-50 to 0-10,000 ppm	0-100 ppm to 0-100%	0-50,000 ppm
b. Accuracy:	+ 2%	+ 3% of Full Scale	+ 1% of Full Scale	1%	+ 2%
c. Calibration Error:		+ 2% of Full Scale	< 0.5% of Full Scale	1%	Not available
d. Zero Drift:	0	+ 2% of Full Scale/24 hrs	< 2%/Month	1%/24 hrs	+ 2% F.S./24 hrs
e. Span Drift:	0	+ 2% of Full Scale/24 hrs	< 2%/Month	1%/24 hrs	+ 2% F.S./24 hrs
f. Repeatability:	1%	+ 2% of Full Scale	1/2% of Full Scale	1/2%	+ 2%
g. Response Time:	75 sec.	95% < 1 min for 100 ft. sample line	Typical 3 sec. adjustable 1 sec. to 1 min	5 sec + sample transport time	30 sec.
h. Operational Period:	> 168 hrs	168 hrs	720 to 2160 hrs	> 168 hrs	168 hrs
5. Operational Requirements					
a. Temperature Range:	20 - 110°F	-20 - 110°F	-40 - 125°F	40 - 120°F	40 - 110°F
b. Calibration:	Optical filters or calibration gases	Dynamic gas calibration	Dynamic complete system incremental calibration using gases	Calibration gases	Calibration gases
c. Warm-up Time:	~ 1 hr	2 hrs	Continuous operation	30 min.	Not available
d. Maintenance:	Clean windows about once a month, replace chart paper	Weekly calibration, sample pumps & filters	Monthly preventative maintenance	Calibration check sample system maintenance	Not available
e. System Requirements:	115 V, 60 Hz	110 VAC, 80 psig instrument air		110V60 Hz2000 watts, 50-100 psig air	110 VAC
6. Special Features:	Insensitive to other contaminants in stack Up to 3 sample points	High efficiency solids removal, permeation distillation system (H <sub>2</sub> O removal) Has no moving parts	In-situ operation complete extensive warranty all parts & labor Integrated analysis across gas stream Measure up to 5 parameters in the same unit		
7. Approximate Cost:	\$10,000 - 15,000	\$11,000	\$5,000 - 40,000 depending on application	\$10,000	Not Available

## SOURCE MONITORING SYSTEMS FOR NOX

1. Mfg. Model:	KVB				
2. Principle of Operation:	Chemiluminescent				
3. Method of Operation:	Continuous				
4. System Performance a. Range: b. Accuracy: c. Calibration Error: d. Zero Drift: e. Span Drift: f. Repeatability: g. Response Time: h. Operational Period:	0-2.5 to 0-10,000 ppm + 2% with cal gas <10% with ref. method $\pm 2\%$ $\pm 1\%/24$ hrs $\pm 1\%/24$ hrs $\pm 1\%$ 10 sec. 168 hrs.				
5. Operational Requirements a. Temperature Range: b. Calibration: c. Warm-up Time: d. Maintenance: e. System Requirements:	20 - 110°F Dynamic gas calculation 1 hr Monthly check of filters & capillaries 115 V, 60 Hz				
6. Special Features:	Automatic calibration of system. Correction of readings to account for dilutions available. Multiple sample points available				
7. Approximate Cost:	\$10-15,000				

Table 3-IV  
SOURCE MONITORING SYSTEMS FOR SO<sub>2</sub>

1. Mfg. Model:	Beckman Model 865 and Reflux Sampling Module	Dupont Model 460	CEA Instruments In-situ Stack Monitor	Environmental Data Corp.	MSA LIRA Model 303 or 202
2. Principle of Operation:	NDIR	UV Photometric	Spectroscopy	In-situ absorption Spectroscopy	NDIR
3. Method of Operation:	Continuous	Continuous	Continuous	Continuous direct viewing industrial gas analyzer	Continuous
4. System Performance					
a. Range:	0-500 to 0-4000 ppm	5 ppm to 100%	0 - 5000 ppm	0-50 to 0-10,000 ppm	0-500 to 0-25%
b. Accuracy:	± 3% of Full Scale	± 2%	+ 5% of Full Scale or + 5% of Full Scale or + 25 ppm, whichever is greater	+ 1% of Full Scale	1%
c. Calibration Error:	± 2% of Full Scale	0	+ 3%/24 hrs	< 0.5% of Full Scale	1%
d. Zero Drift:	± 2% of Full Scale/ 24 hrs	0	+ 5%/24 hrs	< 2%/Month	1%/24 hrs
e. Span Drift:	± 2% of Full Scale/ 24 hrs	0	+ 5%/24 hrs	< 2%/Month	1%/24 hrs
f. Repeatability:	± 2% of Full Scale	1%	Not available	1/2%	1/2%
g. Response Time:	95% < 1 min for 100 ft sample line	15 - 30 sec.	20 sec.	Typical 3 sec adjustable 1 sec to 1 min.	5 sec + sample transport time
h. Operational Period:	168 hrs	> 168 hrs	1000 hrs	720 - 2160 hrs	> 168 hrs
5. Operational Requirements					
a. Temperature Range:	-20 - 110°F	20 - 110°F	-20 - 130°F	-40 - 125°F	40 - 120°F
b. Calibration:	Dynamic gas calibration 2 hrs	Optical filters or calibration gases	Dynamic cal. with internal gas std	Dynamic complete system incremental calibration using gases	Calibration gases
c. Warm-up Time:	Weekly calibration, weekly check on sample pumps and filters	Clean windows about once a month, replace chart paper	Not available	Continuous operation	30 min
d. Maintenance:	110 VAC, 80 psig instrument air	115 V, 60 Hz compressed air, 30-80 psig	Replace light source every 1000 hrs	Monthly preventative maintenance	Calibration check sample system maintenance
e. System Requirements:			120 VAC	115 VAC, 20 amps	110V 60 Hz 2000 watts 50-100
6. Special Features:	High efficiency solids removal Permeation distillation system (H <sub>2</sub> O removal) has no moving parts	Insensitive to other contaminants in stack Up to 4 sample points	In stack test unit, remote monitor Can compensate for up to 80% opacity from particulates No water vapor removal required	In-situ operation Complete extensive warranty, all parts and labor Integrated analysis across gas stream measure up to 5 parameters in the same unit	
7. Approximate Cost:	\$10,000	\$10,000 - 15,000	\$8,400	\$5,000 - 40,000 depending on application	\$10,000

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SOURCE MONITORING SYSTEMS FOR SO<sub>2</sub>

1. Mfg. Model:	KVB Continuous Monitor				
2. Principle of Operation:	UV Photometric				
3. Method of Operation:	Continuous				
4. System Performance	5 ppm to 100%				
a. Range:	± 2%				
b. Accuracy:	± 1% per 24 hrs				
c. Calibration Error:	± 1% per 24 hrs				
d. Zero Drift:	± 1%				
e. Span Drift:	30 sec.				
f. Repeatability:	168 hrs.				
g. Response Time:					
h. Operational Period:					
5. Operational Requirements	20 - 110°F				
a. Temperature Range:	Dynamic gas calculation				
b. Calibration:	1 hr				
c. Warm-up Time:	Clean optics monthly				
d. Maintenance:	115 V, 60 Hz				
e. System Requirements:					
6. Special Features:	Automatic calibration Automatic correction of readings to account for dilution available. Multiple sample points available.				
7. Approximate Cost:	\$15,000				

Table 3-V

SOURCE MONITORING SYSTEMS FOR NOX AND SO<sub>2</sub>

1. Mfg. Model:	Beckman Models 451 & 865 and Reflux Sampling Module	Dynasciences P 101 R	Dynasciences P 101 D	MSA LIRA Model 202 or 303	EDC
2. Principle of Operation:	Chemiluminescent & NDIR	Electro-Chemical	Electro-Chemical	NDIR	Same as NOx, SO <sub>2</sub>
3. Method of Operation:	Continuous	Continuous	Continuous	Continuous	Same as NOx, SO <sub>2</sub>
4. System Performance					
a. Range:	0-10 to 0-10,000 ppm NOx 0-500 to 0-4,000 ppm SO <sub>2</sub>	0-50,000 ppm	0-150,000 ppm	0-100ppm; 0-100% NO 0-500ppm; 0-25% SO <sub>2</sub>	Same as NOx, SO <sub>2</sub>
b. Accuracy:	+ 3% of Full Scale	+ 2%	+ 2%	1%	"
c. Calibration Error:	+ 2% of Full Scale	Not available	Not available	1%	"
d. Zero Drift:	+ 2% of Full Scale/ 24 hrs	+ 2% of Full Scale/ 24 hrs	+ 2%	1%/24 hrs	"
e. Span Drift:	+ 2% of Full Scale 24 hrs	+ 2% of Full Scale/ 24 hrs	+ 2%	1%/24 hrs	"
f. Repeatability:	+ 2% of Full Scale	+ 2%	+ 2%	1/2%	"
g. Response Time:	95% < 1 min for 100 ft. sample line	30 sec.	30 sec.	5 sec + Sample trans- port time	"
h. Operational Period:	168 hrs			> 168 hrs	"
5. Operational Requirements					
a. Temperature Range:	-20 - 110°F	40 - 110°F	40 - 110°F	40 - 120°F	Same as NOx, SO <sub>2</sub>
b. Calibration:	Dynamic gas calibration 2 hrs			Calibration gases	"
c. Warm-up Time:	Weekly calibration, weekly check on sample pumps & filters			30 min	"
d. Maintenance:	110 VAC, 80 psig instrument air	110 VAC	110 VAC	Calibration check sample system maintenance	"
e. System Requirements:				110V 60 Hz 2000 watts 50 - 100 psig air	"
6. Special Features:	High efficiency solids removal Permeation distilla- tion system (H <sub>2</sub> O removal) has no moving parts	Refrigerated sample conditioner	Diffusion sampling		
7. Approximate Cost:	\$16,000	Not available	Not available	\$13,000	

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SOURCE MONITORING SYSTEMS FOR NOX AND SO<sub>2</sub>

1. Mfg. Model:	KVB Continuous Monitor				
2. Principle of Operation:	UV Photometric and Chemiluminescent unit				
3. Method of Operation:	Continuous				
4. System Performance	0-2.5 to 0-10,000 ppm NO 5 ppm to 100% SO <sub>2</sub> + 2% + 2% + 1% / 24 hr + 1% / 24 hr + 1% 30 sec > 168 hrs				
5. Operational Requirements	-20 to 110°F Dynamic gas calibration 1 hr Clean optics, check filters & capillaries 115V, 60Hz				
6. Special Features:	Automatic calibration/ correction of readings to account for dilu- tion available. Multiple sample points available.				
7. Approximate Cost:	\$10-15,000				

Table 3-VI

## SOURCE MONITORING SYSTEMS FOR HYDROCARBONS

1. Mfg. Model:	Beckman Model 400 and Reflux Sampling Module	Environmental Data Corp.	MSA LIRA Model 202 or 303	KVB	
2. Principle of Operation:	Flame Ionization Detector	In-situ Absorption Spectroscopy	NDIR or HFID	NDIR or FID	
3. Method of Operation:	Continuous	Continuous Direct Viewing Industrial Gas Analyzer	Continuous	Continuous	
4. System Performance					
a. Range:	0-5 ppm to 0-10% as Methane	0-50 ppm to 0-10,000 ppm	0-1000, 0-10,000 ppm	0-5 ppm to 0-10%	
b. Accuracy:	+ 3% of Full Scale	+ 1% of Full Scale	1%	+ 3% of Full Scale	
c. Calibration Error:	+ 2% of Full Scale	≤ 0.5% of Full Scale	1%	+ 2% of Full Scale	
d. Zero Drift:	+ 2% of Full Scale/24 hrs	≤ 2%/month	1%/24 hrs	+ 1%/24 hrs	
e. Span Drift:	+ 2% of Full Scale/24 hrs	≤ 2%/month	1%/24 hrs	+ 1%/24 hrs	
f. Repeatability:	+ 2% of Full Scale	1/2%	1/2%	+ 2% of Full Scale	
g. Response Time:	95% < 1 min for 100 ft. sample line	Typical 3 sec; adjustable 1 sec to 1 min	5 sec + sample transport time	30 sec	
h. Operational Period:	168 hrs		> 168 hrs	> 168 hrs	
5. Operational Requirements					
a. Temperature Range:	-20 - 110°F	-40 - 125°F	40 - 120°F	-20 to 110°F	
b. Calibration:	Dynamic Gas Calibration	Dynamic complete System Incremental Calibration Using Gases	Calibration Gases	Dynamic gas cal.	
c. Warm-up Time:	2 hrs	Continuous operation	30 min	2 hrs	
d. Maintenance:	Weekly calibration weekly check on sample pumps & filters	Monthly preventative maintenance	Calibration check sample system maintained	Monthly check of filters and pumps	
e. System Requirements:	110 VAC, 80 psig instrument air	115 VAC, 20 amp	110V 60Hz 2000 watts, 50 - 100 psig air	110V, 60Hz	
6. Special Features:	High efficiency solids removal Permeation distillation system (H <sub>2</sub> O removal) has no moving parts	In-situ operation complete extensive warranty - all parts and labor Integrated analysis across gas stream measure up to 5 parameters in the same unit		Automatic calibration available. Multiple sample points available.	
7. Approximate Cost:	\$9,000	\$5,000 - 40,000 depending on application	\$10,000	\$10,000	

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Table 3-VII

## SOURCE MONITORING SYSTEMS FOR CO

1. Mfg. Model:	Beckman Model 865 and Reflux Sampling System	Environmental Data Corp.	MSA LIRA Model 202 or 303	KVB	
2. Principle of Operation:	Infrared	In-situ Absorption Spectroscopy	NDIR	NDIR	
3. Method of Operation:	Continuous	Continuous direct viewing industrial gas analyzer	Continuous	Continuous	
4. System Performance					
a. Range:	0-50 ppm to 0-100%	0-50 ppm to 0-10,000 ppm	0-50 ppm, 0-10%	0-50 ppm, 0-100%	
b. Accuracy:	+ 3% of Full Scale	+ 1% of Full Scale	1%	+ 3% of Full Scale	
c. Calibration Error:	+ 2% of Full Scale	< 0.5% of Full Scale	1%	+ 2% of Full Scale	
d. Zero Drift:	+ 2% of Full Scale/24 hrs	< 2%/Month	1%/24 hrs	+ 2% of Full Scale/24 hrs	
e. Span Drift:	+ 2% of Full Scale/24 hrs	< 2%/Month	1%/24 hrs	+ 2% of Full Scale/24 hrs	
f. Repeatability:	+ 2% of Full Scale	1/2%	1/2%	+ 2% of Full Scale	
g. Response Time:	95% < 1 min for 100 ft sample line	Typical 3 sec; adjustment 1 sec to 1 min	5 sec + sample transport time	-30 sec	
h. Operational Period:	168 hrs		> 168 hrs	> 168 hrs	
5. Operational Requirements					
a. Temperature Range:	-20 - 110°F	-40 - 125°F	40 - 120°F	-20 to 110°F	
b. Calibration:	Dynamic Gas Calibration	Dynamic Complete System Incremental Calibration using gases	Calibration Gases	Dynamic gas calibration	
c. Warm-up Time:	2 hrs	Continuous operation	30 min.	2 hr	
d. Maintenance:	Weekly calibration weekly check on sample pumps & filters	Monthly preventative maintenance	Calibration check sample system maintenance	Monthly check on filters, pumps	
e. System Requirements:	110 VAC, 80 psig instrument air	115 VAC, 20 amps	110V 60 Hz 2000 watts 50-100 psig air	110V, 60Hz	
6. Special Features:	High efficiency solids removal. Permeation distillation system (H <sub>2</sub> O removal) has no moving parts.	In-situ operation complete extensive warranty - all parts and labor. Integrated analysis across gas stream. Measure up to 5 parameters in the same unit.		Automatic calibration and correction of readings to account for dilution available. Multiple sample points available.	
7. Approximate Cost:	\$10,000	\$5,000 - 40,000 depending on application	\$10,000	\$10,000	

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Table 3-VIII

## SOURCE MONITORING SYSTEMS FOR OPACITY

1. Mfg. Model:	Forney Engineering Model LSM - 1	Environmental Data Corp.	Lear - Siegler RM - 4	
2. Principle of Operation:	Photometric	Split Beam, Double Pass Transmissometer	Duel Beam Transmissometer	
3. Method of Operation:	Continuous Direct viewing	Continuous Direct Viewing Industrial Gas Analyzer	Continuous	
4. System Performance				
a. Range:	0 - 100% Opacity	0-10% to 0-100% Opacity	0-100% Opacity	
b. Accuracy:	Not available	+ 1% Full Scale	+ 3% Full Scale	
c. Calibration Error:	Not available	< 0.5% Full Scale	Not available	
d. Zero Drift:	1%	< 2%/month	Not available	
e. Span Drift:	1%	< 2%/month	Not available	
f. Repeatability:	Not available	1/2%	Not available	
g. Response Time:	4.5 sec	Typical 3 sec; adjustable 1 sec to 1 min	1 sec	
h. Operational Period:	4 weeks		4 weeks	
5. Operational Requirements				
a. Temperature Range:	0 - 150°F	-40 - 125°F	0 - 100°F	
b. Calibration:	Automatic, optical	Dynamic complete system calibration	Automatic, optical	
c. Warm-up Time:	Not available	Continuous Operation	Monthly checks	
d. Maintenance:	Checks for cleanliness of apparatus, especially lenses	Monthly preventative maintenance		
e. System Requirements:	103.5 - 126.5 V	115 VAC, 20 amps	115 V, 60 Hz	
6. Special Features:	In-situ	In-situ operation. Complete extensive warranty - all parts and labor. Integrated analysis across gas stream. Measure up to 5 parameters in the same unit.	In-situ operation	
7. Approximate Cost:	\$6,000	\$2,000 - 15,000 depending upon application	\$8,000	

Table 3-IX  
SOURCE MONITORING SYSTEMS FOR PARTICULATES IN TERMS OF WEIGHT

1. Mfg. Model:	GCA/Technology PMM - 1	Lear Siegler PM/ARGOS 1			
2. Principle of Operation:	Beta-absorption	Beta-absorption			
3. Method of Operation:	Intermittent cycle adjustable	Intermittent cycle adjustable			
4. System Performance					
a. Range:	.001-10 mg/m <sup>3</sup>	1-100 mg/m <sup>3</sup>			
b. Accuracy:	0.1 mg	± 10% concentration			
c. Calibration Error:	N/A	< ± 4%			
d. Zero Drift:	N/A	< ± 4%			
e. Span Drift:	N/A	N/A			
f. Repeatability:	N/A	N/A			
g. Response Time:	1-99 min	N/A			
h. Operational Period:	N/A	168 hrs			
5. Operational Requirements					
a. Temperature Range:	Ambient	-20 - +50°C			
b. Calibration:					
c. Warm-up Time:					
d. Maintenance:		6 Insp. & Main't/yr			
e. System Requirements:	115 VAC, 60 Hz, 500 W	220 VAC, 60 Hz			
6. Special Features:	Direct mass & mass concentration read- out. All solid state electronics	Direct mass & mass concentration read- out.			
7. Approximate Cost:	\$15,000	\$25,000			

capital cost will be required per month to completely maintain the system. Of course the maintenance required is a function of the application of environmental conditions, corrosiveness of the flue gas, etc.

The cost data submitted indicate that monitoring systems for measuring a single gaseous emission are available in a range of from \$5,000 to \$40,000 depending on the installation. The most frequently quoted cost is approximately \$10,000 for a single gaseous measurement. The cost for two measurements ( $\text{NO}_x$  and  $\text{SO}_2$ ) is slightly higher; \$3,000 to \$5,000 greater than a single measurement. The cost for installing a system for measuring opacity ranges from \$2,000 to \$15,000. It should be emphasized that these prices are FOB factory for so-called "minimum systems". Addition of optional features such as automatic calibration or other automatic functions, alarms, or additional sample points in the case of extractive systems, can significantly increase the costs. Many of these systems are tailor-made for a specific application, and the engineering required will also affect the price. Finally, the cost of installation and start-up must also be considered as it is highly variable, depending on location, application, and complexity of the system.

The most feasible technique for measuring particulate mass appears to be the beta attenuation method. The operation of these instruments is based on the principle of beta absorption which yields an accurate mass concentration independent of the particulate characteristics. Consequently, their performance is not affected by variations in particulate composition, optical characteristics, particle size, or other physical and chemical parameters of the collected sample. The price range for a continuous particulate monitoring system is from \$15,000 to \$25,000. The existing particulate measurement techniques employ extractive sampling. At least one manufacturer is currently developing a system which will be installed in the stack and will not require an extractive sampling system for operation. The manufacturer estimates that this particulate monitor will be available within one year.

A significant cost savings can be realized where several devices in close proximity are to be monitored with an extractive system. A single sample conditioning system and instrument package can be used with automatically sequenced valves on the sample lines to obtain the required data.

The additional cost above the basic continuous monitor system price would be only about \$400 per additional sample (for a 50-foot line length).

The measurement units of all the gaseous pollutants are in terms of parts per million, or percent by volume. As a result, any change in the level of excess air in the flue gas due to variable operating conditions or leakage into the duct results in a lowering of the measured concentration of the pollutant. This result is very misleading since on a mass basis the level of pollutant emissions may not have changed. This dilution can be taken into account, however, by measuring the level of oxygen in the sample and correcting the concentration of pollutant to a constant reference level such as 3% O<sub>2</sub>. Naturally, the oxygen should be measured at the same locations as are the emissions. With the data in this form, comparisons can readily be made on an absolute basis, and the data presented in a meaningful form. As an added advantage, O<sub>2</sub> measurement can provide valuable operational information. There are a number of oxygen analyzers commercially available which can readily be added to the extractive systems described. They range in price from \$1,000 to \$3,000. An in situ oxygen analyzer is also available. This probe-type analyzer consists of a heated electrochemical cell which is inserted directly into the flue gas duct. Because of stratification in the duct, the proper location of this type of probe is very important. Price of the probe is in the \$3,000 to \$4,000 range.

#### 4.0 EMISSION RATES IN MASS UNITS

The continuous monitor systems discussed in Section 3 all provide volumetric concentration of the pollutants measured. Measurement of the mass rate of pollutant flow may be desired for purposes of total damage estimates or regulation compliance. This can be done with existing technology. A variety of techniques can be used. In the absence of any definitive information from monitor manufacturers, the use of standard process industry computing modules was considered for this study.

##### 4.1 Mass Rate of Emissions from Stacks

Continuous readout of the mass rate of emissions is possible for several of the source categories discussed in Section 2. In order to accomplish this for gaseous pollutants (NO<sub>x</sub>, SO<sub>2</sub>, CO, and hydrocarbons), the continuous monitors described in Section 3, which provide volumetric concentration measurements, must be combined with either stack or fuel flow instruments and appropriate calculational networks. At least one of the manufacturers contacted stated that they offer this option. The approach for particulates, while related, requires the use of beta instrumentation in conjunction with stack and/or fuel measurements.

4.1.1 Stack Flow Approach for Gaseous Pollutants. The determination of stack gas flow rate can be accomplished by measuring the velocity and temperature distribution over equal area sectors at a given station and summing the results. Standard procedures for selecting the number and location of these sectors are well documented<sup>(15)</sup>. In order to use a single measurement point to characterize the flow, the velocity distribution should be determined and a correction factor derived for the single point measurement<sup>(3)</sup>. After determination of a correction factor, the volumetric flow is given by

$$Q_e = k_1 V A_d \quad (4.1)$$

where  $Q_e$  = volumetric flow rate, ft<sup>3</sup>/min  
 $k_1$  = empirical constant  
 $V$  = velocity, ft/min  
 $A_d$  = duct area, ft<sup>2</sup>

Several methods for determining the velocity are available. These include pitot probes, vane type meters, propeller meters and thermal meters. Of these, the preferred type for flue gas environment is the pitot probe<sup>(15)</sup>.

In order to utilize the pitot probe in a continuous monitor, a pressure transmitter and temperature probe must also be used. Figure 7 is a schematic of a continuous monitor system employing a pitot probe for stack flow determination. The basic components required are pitot probe, differential pressure transmitter, pressure-to-current converter, thermocouple, thermocouple transmitter, division module, square root transmitter, multiplication module, and recorder.

The basic relations for each component are:

<u>Output-Input Relation</u>	<u>Component Code</u>
$E_1 (\Delta p) = p_a (\Delta p)$	P/I
$E_2 = K_2 T$	TCT
$E_3 = K_3 \left( K_4 E_1 / K_5 E_2 \right)$	ADB
$E_4 = K_6 \sqrt{E_3}$	SRT
$E_6 = K_7 K_8 E_4 K_9 E_5$	AXB

The basic equations from which the module constants must be derived are:<sup>(15)</sup>

$$V = 1096.5 \sqrt{\Delta p / \rho} \quad (4.2)$$

Multiplying by  $K_1 \rho A_d$  to get mass flow gives:

$$\dot{m}_e = 65,790 K_1 A_d \sqrt{\rho \Delta p} \quad (4.3)$$

For a molecular weight of 29 and a pressure of 1 atm,

$$\dot{m}_e = 414,700 K_1 A_d \sqrt{\Delta p / T} \quad (4.4)$$

where

- $V$  = exhaust velocity, ft/min
- $\dot{m}_e$  = exhaust mass flow, lb/h
- $\Delta p$  = pitot pressure difference, inches  $H_2O$
- $T$  = temperature, °R
- $A_d$  = duct area,  $ft^2$
- $K_1$  = empirical constant determined by probing the duct at this station

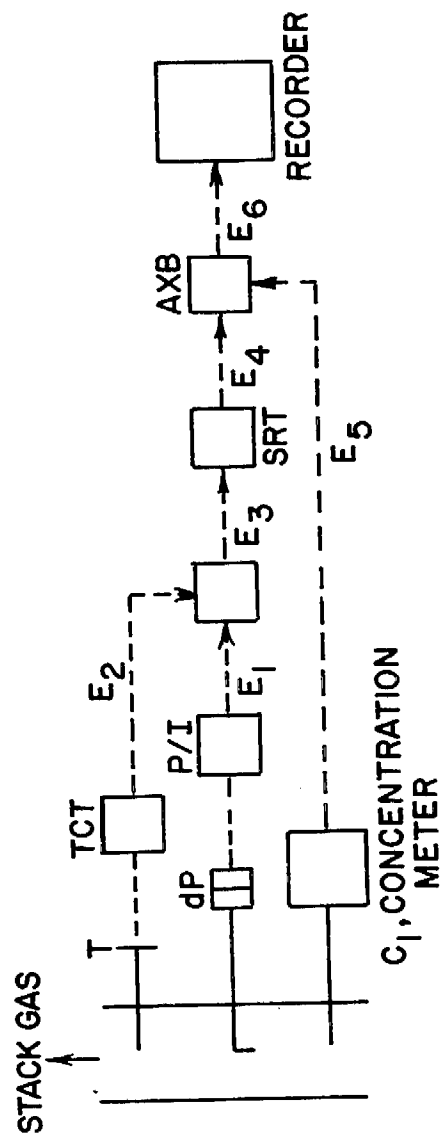


FIGURE 7. SCHEMATIC OF MASS MONITOR CALCULATION NETWORK FOR STACK VELOCITY MEASUREMENT.

The mass flow of pollutant "1" is then given by

$$\dot{m}_{c_1} = C_1 \frac{M_{c_1}}{M_e} \dot{m}_e \quad (4.5)$$

where  $M_{c_1}$  = the molecular weight "1" (e.g., 46 for  $\text{NO}_2$ )  
 $M_e$  = the molecular weight of the exhaust gas  
 $C_1$  = volume concentration of "1" from the continuous monitor

All the components shown are standard process instrumentation components. Estimates for complete systems range from \$1450 to \$1600 above the cost of the basic continuous monitor packages.

4.1.2 Fuel Flow Approach for Gaseous Pollutants. An alternative to measuring the stack gas flow rate is to measure the fuel flow, flue gas oxygen, and pollutant concentration. Any number of reliable fuel flow meters can be used. It will be assumed for purposes of this study that the fuel flow meter is already installed and provides a signal of the form:

$$E_7 = E_7 (\dot{m}_f^2) \quad (4.6)$$

(such as would occur for a venturi meter with an electronic differential pressure transmitter). With this signal, the arrangement of Figure 8 would provide an indication of the mass flow rate of pollutant "1".

The basic component relations of Figure 8 are

<u>Output-Input Relation</u>	<u>Component Code</u>
$E_8 = \sqrt{E_7}$	SRT
$E_{11} = K_{10} K_{11} E_9 K_{12} Z_1$	AXB <sub>1</sub>
$E_{12} = E_{11} + Z_2$	SIM <sub>1</sub>
$E_{13} = K_{13} (E_9 / K_{14} E_{12})$	ADB <sub>1</sub>
$E_{15} = E_{13} + Z_5$	SIM <sub>2</sub>
$E_{17} = K_{15} K_{16} E_{15} K_{17} Z_6$	AXB <sub>3</sub>
$E_{16} = K_{18} K_{19} E_{13} K_{20} Z_7$	AXB <sub>2</sub>



<u>Output-Input Relation</u>	<u>Component</u>
$E_{18} = E_{16} + E_{17} + Z_3$	$SIM_3$
$E_{19} = K_{21} (E_{18}/K_{22}Z_4)$	$ADB_2$
$E_{20} = K_{23}K_{24}E_{19}K_{25}E_{10}$	$AXB_4$
$E_{21} = K_{26}K_{27}E_{20}K_{28}E_8$	$AXB_5$

The basic combustion relations from which the instrument constants need selection are:

$$X = \frac{(4.77 + .94E)[O_2]}{100 - (4.77)[O_2]} \quad (4.7)$$

$$\frac{\dot{m}_e}{\dot{m}_f} = \frac{44.01 + 32.00X + (3.77)(28.02)(1 + .25E + X)}{12.01 + 1.008E} \quad (4.8)$$

and

$$\dot{m}_{c_1} = \frac{M_{c_1}}{M_e} C_1 \dot{m}_f \frac{\dot{m}_e}{\dot{m}_f} \quad (4.9)$$

where  $E$  = hydrogen/carbon atom ratio in fuel  
 $[O_2]$  = measured flue gas oxygen concentration, ppm by volume, dry  
 $\dot{m}_e$  = exhaust gas mass flow (e.g., lb/h)  
 $\dot{m}_f$  = fuel mass flow (e.g., lb/h)  
 $C_1$  = measured concentration of pollutant "1"  
 $M_{c_1}$  = molecular weight of pollutant "1"  
 $M_e$  = molecular weight of flue gas  
 $\dot{m}_{c_1}$  = mass flow of pollutant "1" from stack (e.g., lb/h)

These relations apply for the case of a hydrocarbon fuel. In order to utilize the block diagram of Figure 8, an average, constant value for  $E$  and for  $M_e$  must be known and used. If the fuel consists of CO and diluents such as  $N_2$  and  $CO_2$  of relative fractions  $Z$ ,  $Y$ ,  $W$ , then equations (4.7) and (4.8) become:

$$X = \frac{[O_2]}{100 - 4.77[O_2]} (4.77 + 2.89Z + W + Y + .94E) \quad (4.10)$$

$$\frac{\dot{m}_e}{\dot{m}_f} = \frac{(1 + Z + W)(44.01) + (X)(32.00) + [(1 + .25E + X + .5Z)(3.77) + Y](28.02)}{12.01 + (E)(1.008)} \quad (4.11)$$

which results in the same basic instrument block diagram, so long as the fuel concentrations are known and constant.

The complexity of the instrument arrangement is somewhat greater for the fuel flow rate method than measurement of the stack gas flow rate. Combination of several of the elements and inclusion of scaling modules can result in a much simpler installation than that of Figure 8. Estimates for this type of monitor computational network range from \$1,700 to \$1,900. Calibration and maintenance requirements are of course greater due to the greater number of instruments.

4.1.3 Particulates. Continuous measurement of particulate mass flow presents many difficulties not encountered when measuring gaseous pollutants. Opacity can be measured by any of several commercially available instruments discussed in Section 3. This parameter has been accepted by the EPA in their proposed standards<sup>(3)</sup> as being representative of the particulate loading. However, since this parameter is proportional to the particle number density and particle size, it does not provide a measure of the mass concentration<sup>(12)</sup>. The only mass concentration meter used extensively is based on absorption of beta radiation by a particulate sample collected on a filter. One such device, discussed in Section 3, is automated to collect a 5-minute sample on a 9 cm<sup>2</sup> filter area, advance the filter tape to a beta source and geiger counter, and electronically calculate the concentration from the number of geiger counter events and the measured gas flow rate. The result can be given as grains/ft<sup>3</sup>. All that remains then is to use that output with either the stack flow circuit of Figure 7 or the fuel flow-flue gas oxygen circuit of Figure 8 to get the total particle emission mass rate. For example if a signal proportional to the concentration is obtained from the particulate meter:

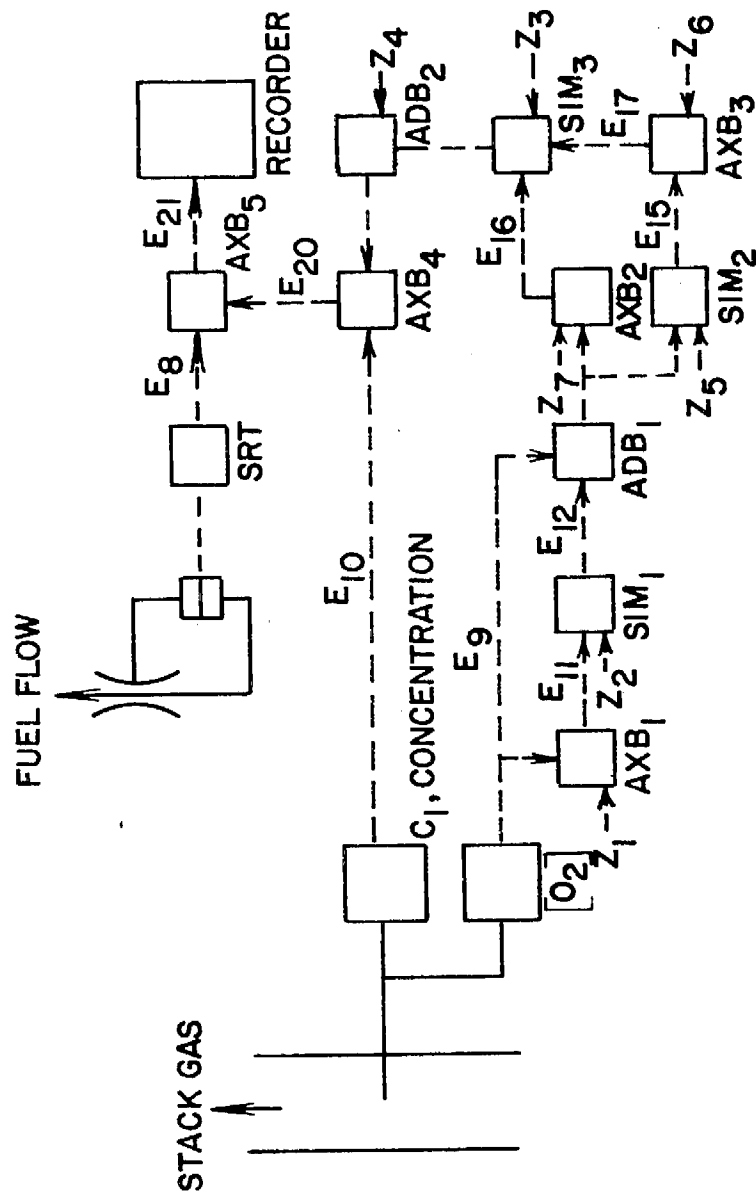


FIGURE 8. SCHEMATIC OF MASS MONITOR CALCULATIONAL NETWORK FOR FUEL FLOW RATE AND FLUE GAS OXYGEN MEASUREMENT.

$$\rho_p = k_p E_p \quad (4.12)$$

where  $\rho_p$  = particulate density, grains/ft<sup>3</sup>  
 $E_p$  = instrument signal  
 $k_p$  = proportionality constant

Then the mass flow is given by:

$$\dot{m}_p = .00857 \rho_p Q_e \frac{p_0 T_e}{p_e T_0} \quad (4.13)$$

where  $\dot{m}_p$  = particulate mass rate, lb/h  
 $p_0$  = standard pressure, atm  
 $T_0$  = standard temperature, °R  
 $p_e$  = stack pressure, atm  
 $T_e$  = stack temperature, °R

Figure 9 is a block diagram of this type of installation. The total additional cost should consist of two additional calculational modules and the particulate meter and sampling system itself. Of course, in order to gain a representative sample, the probe must be isokinetic and if it is at a fixed position, an empirically determined correction factor must be used. The probe of one such instrument has a programmed variation in probe position in order to obtain an averaged sample.

A method of determining mass flow has been discussed which involves the processing of analog signals. Digital methods can also be used but will be more expensive unless several devices are processed or unless a computer is available at no cost. The method considered uses "off-the-shelf" process industry components and has a cost of about 10% of the basic monitor cost.

#### 4.2 Other Devices

The mass flow from non-combustion devices such as solvent tanks, cement loading bins, aggregate screening installations which discharge pollutants through an exhaust hood and ducting can also be determined by the

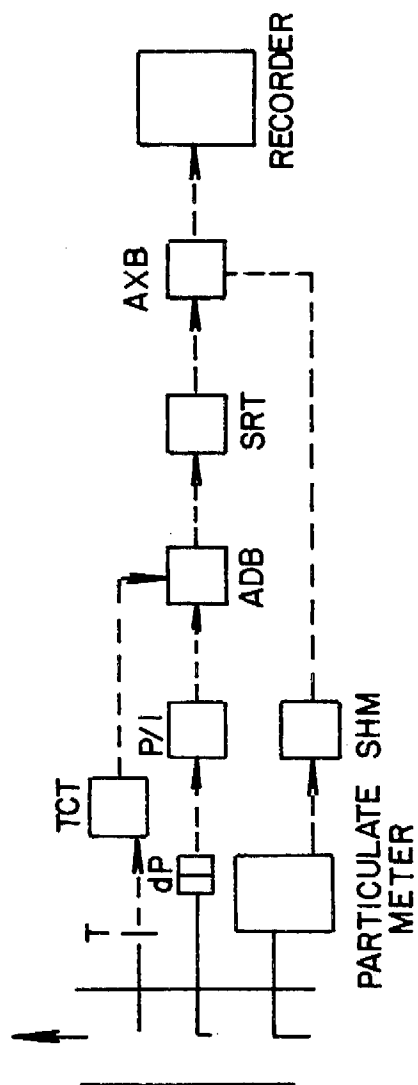


FIGURE 9. SCHEMATIC OF PARTICULATE MASS MONITOR CALCULATIONAL NETWORK.

methods of 4.1.1 and 4.1.3. Since there is no combustion, the fuel flow method of 4.1.2 cannot be used. Instead, the exhaust gas velocity and temperature must be determined as described in those sections. The primary pollutants emitted in this category are hydrocarbons and/or particulates. As discussed previously, devices which have area-distributed emissions do not appear to be amenable to the use of continuous monitors.

## 5.0 DATA HANDLING TECHNIQUES

The problem of data management and reporting is very significant when considering the application of continuous monitors statewide. The processing of data from over 700 sources with an average of two to three contaminants each would present many difficulties if conventional manual recording and reporting were used. The current EPA proposed requirements for emission monitoring<sup>(3)</sup> call for a sampling, analyzing, and data recording cycle of 1 min. for opacity, 15 min. for SO<sub>2</sub>, NOx, and O<sub>2</sub>, and one hour for all others. The most controversial of these is the use of a 1 min. opacity cycle to estimate particulate emissions. Because of the difficulty in relating these parameters, substitution of a particulate meter with its 5-min sampling period may be more satisfactory. The frequency of reporting is four times a year (each calendar quarter) and includes the magnitude of emissions, all periods of excess emissions, and any malfunctions. In addition, the owner or operator is required to maintain a file of all measurements and qualification tests for two years following the measurements. Thus the storage requirement for a single source with the three contaminants listed is 1,260,000 entries identified by type, date, and time. The philosophy behind these frequent sampling requirements appears to be an attempt to record the maximum rate and violations rather than an integrated total. If an integrated total was desired, the sampling frequency and data storage could be markedly reduced.

Several alternatives to manual data handling techniques can be considered. They are: (1) Serviced processing system (SPS) and (2) Real time processing systems.

In each case, the method of data storage is magnetic tape or disc. The method of data analysis and report generation is with a computer (processor) and printer. The display method for the operator differs in that the first method uses continuous monitor recorders, while the real time systems typically use a CRT or similar display.

### 5.1 Serviced Processing System

The SPS requires only the installation of a multiplexer and analog-to-digital converter and tape writer with each continuous monitor or group of continuous monitors. As such, it is the least expensive data handling system and is most suitable for smaller companies or those with only a few

sources. The display is obtained with the standard or mass rate option continuous monitor instruments and recorders. The data storage sequence begins with the tape writer (either cassette or reel). In order to reduce the data, obtain the final storage form and prepare reports, the tapes are collected periodically, taken to a service facility, fed into a tape reader which inputs the data to a processor (computer). The processor is programmed to reduce the data and prepare a report in the proper form. The processor enters the data in the final storage form, magnetic tape or disc. It is anticipated that the storage for smaller users would all be at this service facility and the records would be available for government agency inspection or other usage. The old cassettes or tape reels would be returned to the operator for reuse or storage at that location. A block diagram for this system is shown in Figure 10. Another variation could be a dual cassette tape writer which could be used to relay the information to the service facility by phone lines.

Examples of suitable data acquisition systems were obtained from manufacturers. One such unit multiplexes the analog data from up to 20 sources (channels) and converts it to digital form upon periodic, operator selected intervals. The digitized information is then read onto a cassette or 9-track IBM tape. For the full 20 channels and a 15-minute interval, each cassette would last 65 days. Thus only six cassettes per year would be required for the data storage for three stationary sources having all five pollutants measured. Table 5-I shows the variation of tape life with record interval. Storage of opacity data at the 1-min. frequency required by the EPA standards would increase the number of cassettes to 18 per year.

The estimated cost for this type of system is \$5300 for the physical tape collection option. For the dual tape cassette option, the installed cost would be \$9500. The estimated cost of tape handling, processing, report preparation and distribution and storage would be about \$400/mo.



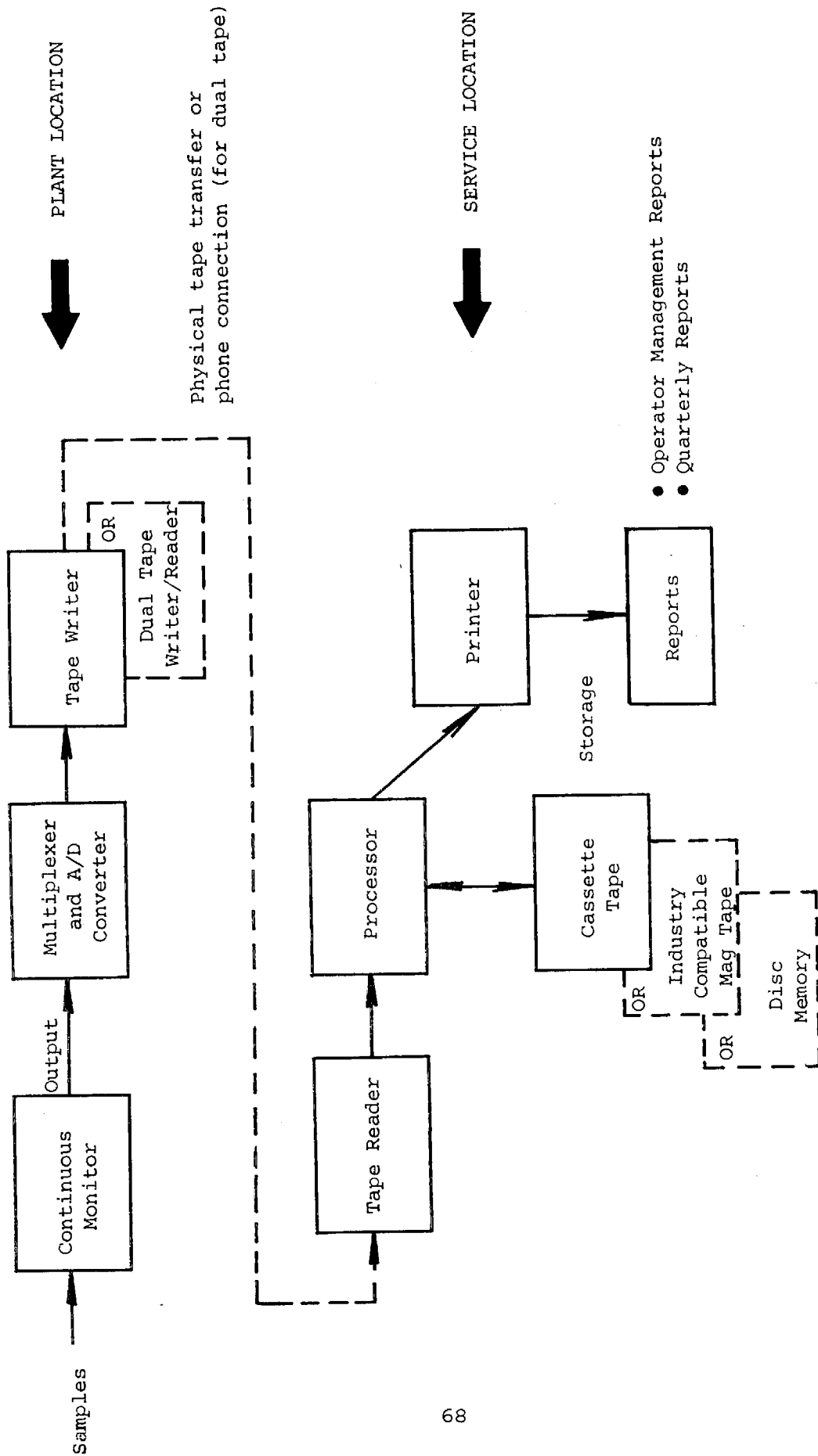


FIGURE 10. SERVICED PROCESSING SYSTEM

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Table 5-I. Variation of Cassette Recording Duration  
Depending upon Data System Initial Setup

Record Interval (Minutes)	Days of Recording Capacity on Cassette			
	10 Analog	10 Analog + 4 Pulse	20 Analog	20 Analog + 4 Pulse
1	9	6.3	4.5	3.7
5	44	31	22	18
10	86	62	43	36
15	126	91	65	54
30	234	180	125	105
60	411	312	234	198

Another data acquisition system to satisfy the requirements of data handling was quoted by another firm. This unit handled 8 channels of data and includes a digital clock channel. The cassette life for a 1 minute recording frequency is 510 hours. The estimated cost was about \$9,000 with an additional \$3,000 for a dual cassette recorder.

## 5.2 Real Time Processing System

The basic technique of this type of system is real time data reduction as opposed to data gathering followed by off-line processing. As a result, it is suitable for installation with many devices because of the greater unit expense and the real time data reduction feature.

Each device is provided with sensors for NO<sub>x</sub>, SO<sub>2</sub>, O<sub>2</sub>, CO, opacity, particulates, unit load, oil fuel flow and/or gas fuel flow. All of the sensors from all sources at a plant are multiplexed for eventual processing by a computer. The real time readouts of reduced, processed data can be located either at each individual plant site or at the central control station. The stations would be connected by either telephone lines or microwave lines. The advantages of this more complex system result basically from the real time data generation capability. In addition to gathering, reducing, and reporting data, the system can provide on-line operating and emission information.

Many different proprietary approaches to designing these systems exist. In general they all provide a centralized information receiving and control capability for emission sources which may be physically separated by large distances. Many special features such as cathode ray tube display, real time data processing and report printing, and telephonic data transmission can be provided.

Cost and reliability will be quite variable depending on the individual manufacturer's system design.

## 6.0 TYPICAL APPLICATIONS

In this section, layouts of several typical systems which show the major components and possible locations of these components for a typical emission source are presented. The device used as an example is a forced draft boiler with a rotary air preheater and an electrostatic precipitator. For purposes of these examples, this boiler is assumed to produce substantial quantities of all five pollutants. Ninety percent of the devices considered have only one or two pollutants but in order to illustrate a system of maximum complexity, all five were considered. Since the sources with more than two pollutants are generally power plants or large refinery heaters, they contribute much more than 10% of the total emissions.

The layouts show the necessary functional units and where they are located in the system rather than attempting to show how each of these functional units operates. The details of how various modules operate is discussed in Section 3.

Four systems are presented, complete and minimum systems which make maximum use of extractive type analyzers and complete and minimum systems that make maximum use of in stack analyzers. The complete systems include all available features so that the most reliable data is obtained with a minimum of maintenance and data handling. That is, all calibration and data recording and reducing occurs automatically, without operator intervention. Conversely, the minimum system requires operator intervention for calibration and data reduction.

### 6.1 Complete Extractive System (Figures 11 and 12)

A series of probes which give a representative sample of gaseous pollutants is used as opposed to a single point probe. Since in most cases there are substantial concentration gradients across a duct, either a multipoint sample system must be used or a representative single point must be located. The EPA has devised a procedure<sup>(3)</sup> for locating multiple sampling points so as to assure a representative sample. Locating the representative point (a point which can vary with load or may not exist at all) requires considerable experimentation. A correctly designed multi-probe system will extract a representative sample under all conditions. Also, with a number of probes, if one probe plugs or otherwise fails, a workable system remains in operation with a moderate degradation in accuracy.

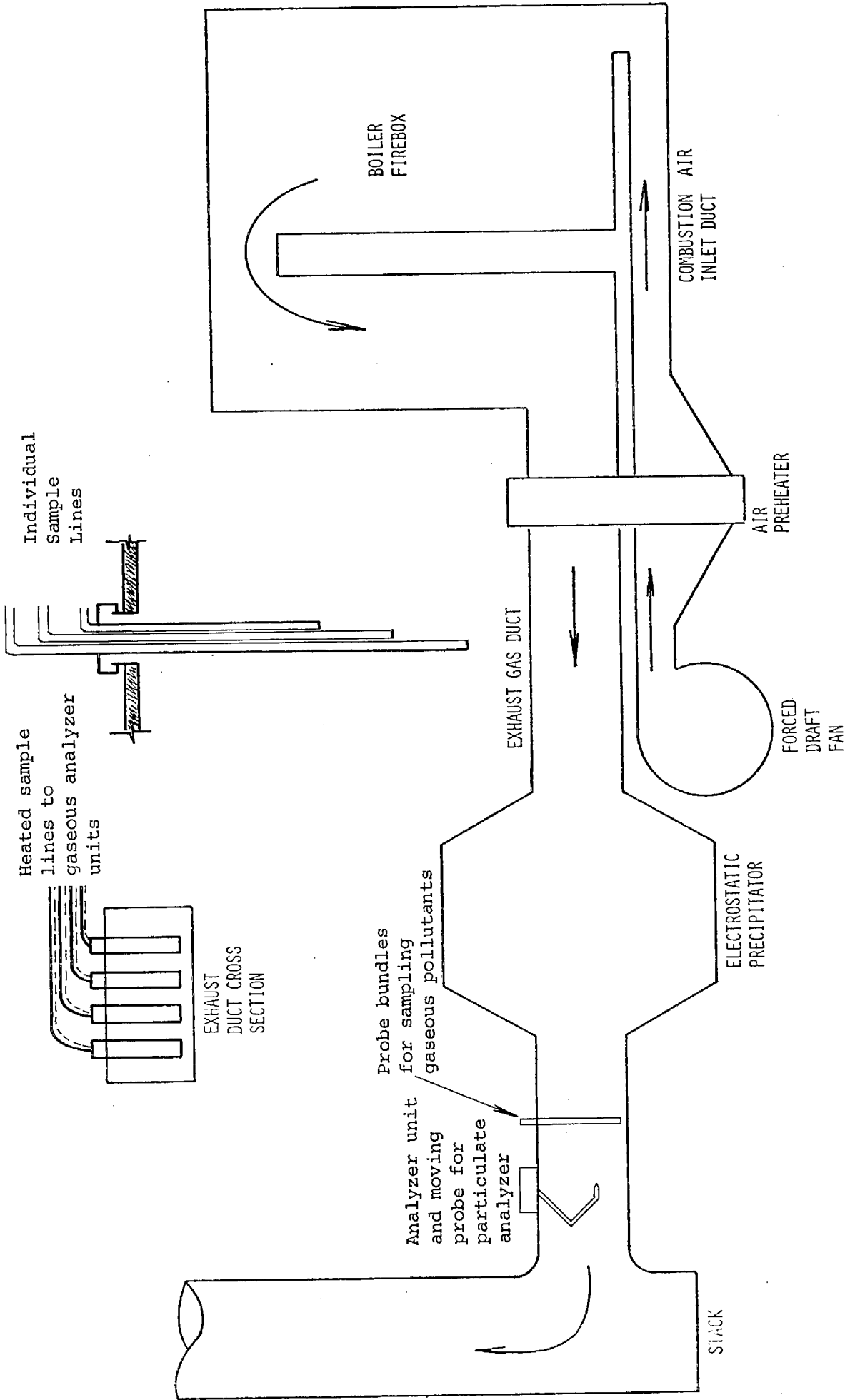


FIGURE 11. COMPLETE EXTRACTIVE SYSTEM: PROBES, SAMPLE LINES, AND PARTICULATE ANALYZER.

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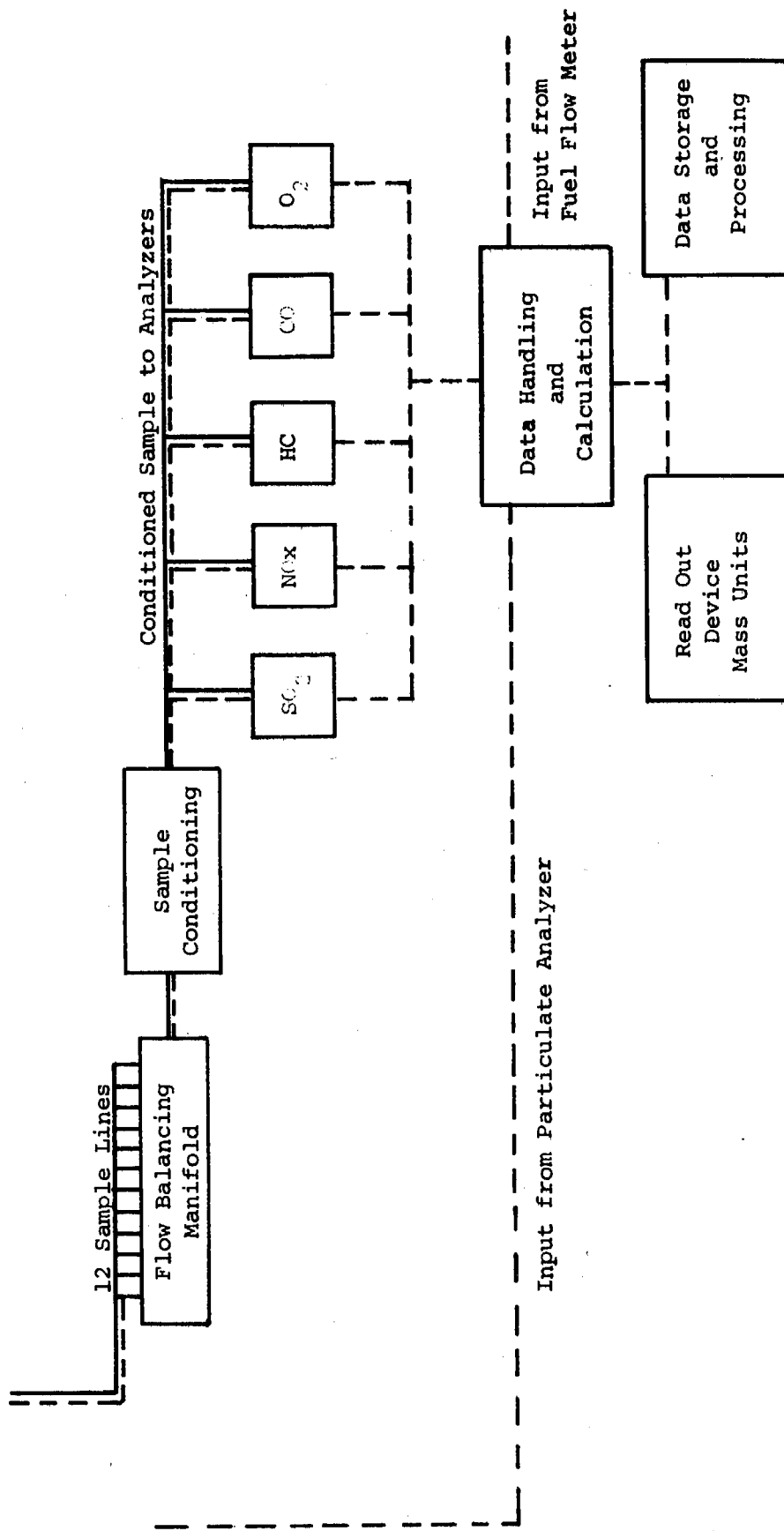


FIGURE 12. COMPLETE EXTRACTIVE SYSTEM: SAMPLE HANDLING, ANALYZERS, DATA HANDLING.

Since there are probes at several locations, it is possible to map out concentration gradients of the various pollutants. Sometimes such information can be used to improve combustion efficiency and locate malfunctions, since, in many cases, concentration gradients which are created at the burner face are retained all the way through the fire box and duct work. For example, high CO readings when there is apparently sufficient combustion air is indicative of a bad burner or burners in a multi-burner installation. Where the CO concentration is considerably higher in one area of the duct than another, the location of the bad burner can be estimated. For example, if the CO concentration is very high in the lower right section of the duct the indication is that a burner in the lower right side of the burner face is malfunctioning.

Since some of the pollutants are water soluble, the sampling system must be designed such that no water is allowed to condense. The easiest way to prevent condensation is to heat the sample lines. Therefore, this system uses heated sample lines between the probe and the sample conditioning module. These lines are electrically trace heated to about 150° to 400°F depending on the gas stream composition (steam trace heating is another possibility in environments where an explosion-proof system is required).

The individual sample lines are brought together in a flow balancing module. The purpose of this module is to assure that an equal volume of sample is pulled through each probe, and hence a representative sample is obtained.

From here the sample flows to a sample conditioning module. In this module the sample is dried and filtered as necessary. For simplicity, the schematic shows only one line running to the instruments, although in practice the samples going to each analyzer are conditioned as necessary for each individual instrument. That is, some analyzers require that the water be removed while for others the water cannot be removed without losing the sample.

An O<sub>2</sub> meter and a fuel flow meter are included. With the excess O<sub>2</sub> level, the fuel flow and the knowledge of the fuel composition, the mass stack flow rate can be calculated, and, as was pointed out

earlier, measurement of the  $O_2$  is very valuable in adjusting a combustion device for maximum efficiency.

The particulate analyzer is equipped with a moving probe which serves the same function as the multiple probe system for the gaseous emissions. As the probe moves across the duct it integrates the particulate concentration gradients continuously. This type of system requires that the analyzer be located at the sampling location at the stack or duct. As was pointed out in Section 3, this type of monitor does not provide a continuous output, but instead samples for five minutes and then analyzes the collected sample.

All of these instruments are automatically calibrated periodically without operator intervention.

The outputs from all the analyzers and the fuel flow meter are fed to the data handling and calculation module. In this unit, the analog signals from the analyzers, which are in concentration units, are input to the calculational network to provide emission information in mass units. This information is transmitted to a strip chart recorder in the control room. The recorder provides the operator with real time information regarding the current emission rates. The same information is sent to a multiplexer, A/D converter and tape writer (data storage and processing module) which stores the emission information and tags it with the date and time.

## 6.2 Minimum Extractive System (Figures 13 and 14)

This system has a single point probe for sampling gaseous emissions. As was pointed out earlier, use of this type of sampling system entails a series of tests to determine a position for the probe such that a representative sample is obtained. Similarly, since a non-moving probe is used, a representative particulate sampling point must be determined (the two representative points do not necessarily coincide).



Heated line from  
single carefully  
located probe to  
gaseous analyzer  
units

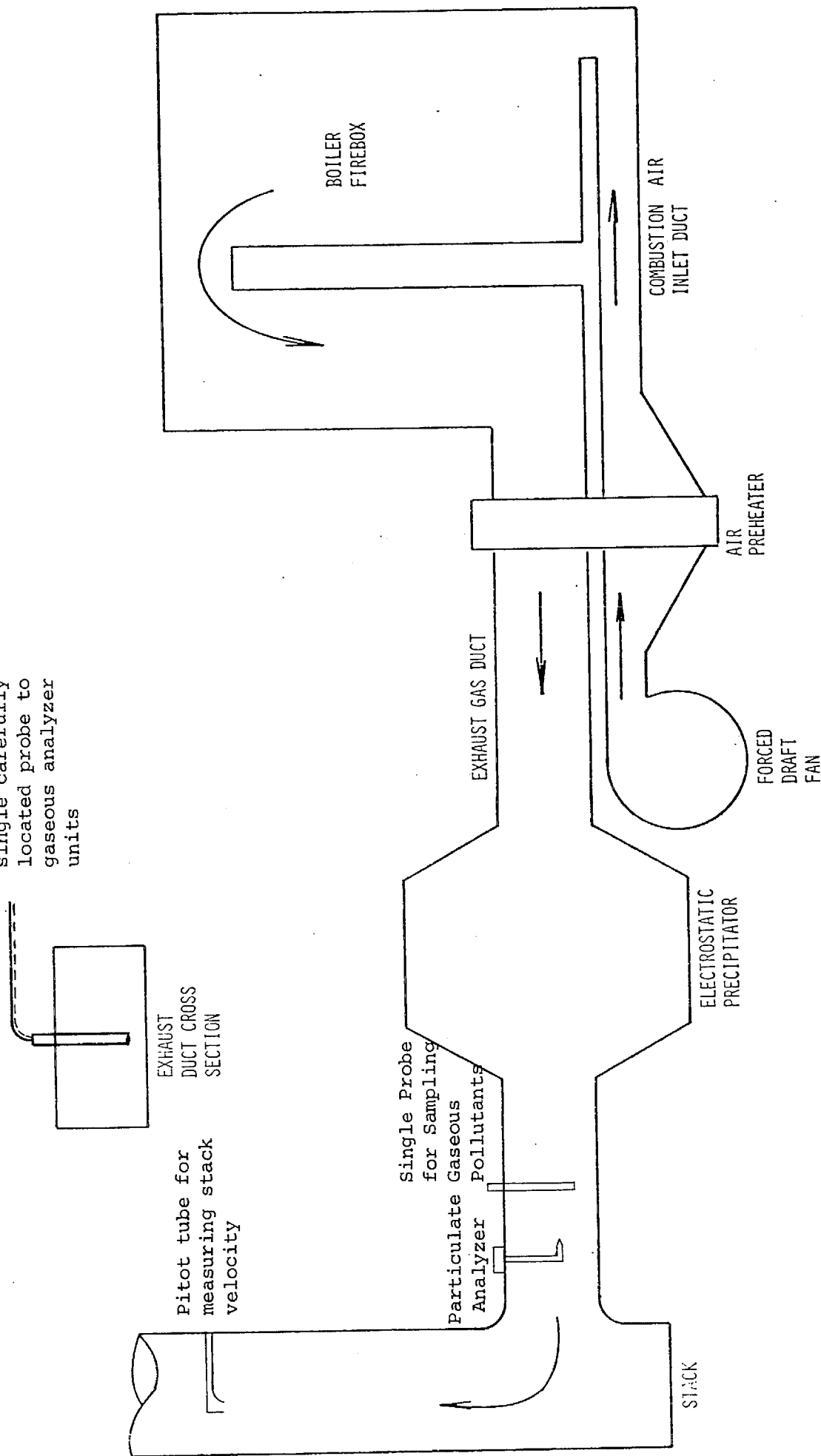


FIGURE 13. MINIMUM EXTRACTIVE SYSTEM: PITOT PROBES, SAMPLE LINES, AND PARTICULATE ANALYZER.

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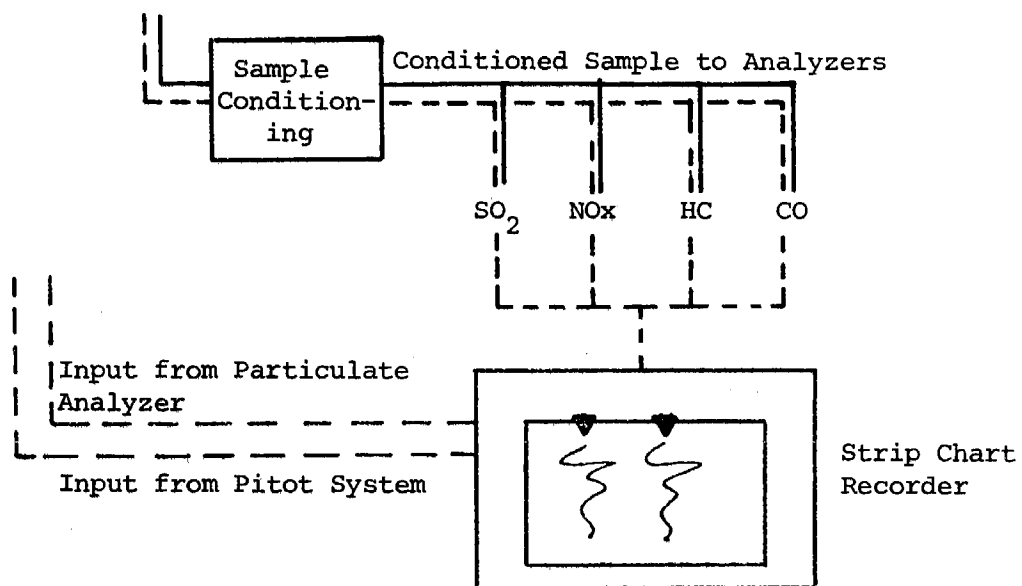


FIGURE 14. MINIMUM EXTRACTIVE SYSTEM: SAMPLE HANDLING, ANALYZERS, AND DATA RECORDING.

The mass flow rate here is measured by using a pitot tube to measure the velocity of the exhaust gas. In order to give an accurate mass flow rate, the velocity measurement must be made at a carefully chosen point so as to assure a representative stack velocity. Additionally, it is advisable to locate the pitot tube a sufficient distance downstream from any flow disturbance such as air preheater wheels, electrostatic precipitators, bends in the duct work, etc., so that such disturbances do not interfere with the velocity measurements. In most cases it is assumed that a point .8 duct diameters downstream from a disturbance is sufficient to allow accurate velocity measurements.<sup>(3)</sup> In this system, the pressure differences measured by the pitot tubes are converted to an electronic signal at the stack.

As in the previous system, the particulate analyzer is located at the stack or duct. A heated line carries the gaseous sample to the sample conditioning module. The outputs from the pitot tube, particulate analyzer, and gaseous pollutant analyzers are recorded on a strip chart recorder.

All instruments in this system are calibrated manually.

This system would require probably three to four full time operators if the stipulated EPA measurement frequencies are met, since all of the data manipulations must be done by hand. As was pointed out in Section 3, a very large number of data points must be stored and used in writing the necessary reports.

### 6.3 Complete In-Stack System (Figures 15 and 16)

In this system opacity,  $\text{SO}_2$ ,  $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{HC}$ , and  $\text{CO}$  are measured optically in the stack. Oxygen is measured with a typical extractive system. Possible alternatives to this method to measure oxygen with a separate in situ oxygen monitor or a  $\text{CO}_2$  monitor if approval of the regulatory agency can be obtained.

A major difference between this system and the extractive system is that opacity rather than particulate concentration is measured. This requires that a series of particulate tests be conducted in order to determine particulate concentration as a function of opacity if the actual mass flow rate or weight concentration of particulates is to be determined.

Unheated sample lines  
to O<sub>2</sub> meter. Multiple  
probes identical to  
those shown in Figure

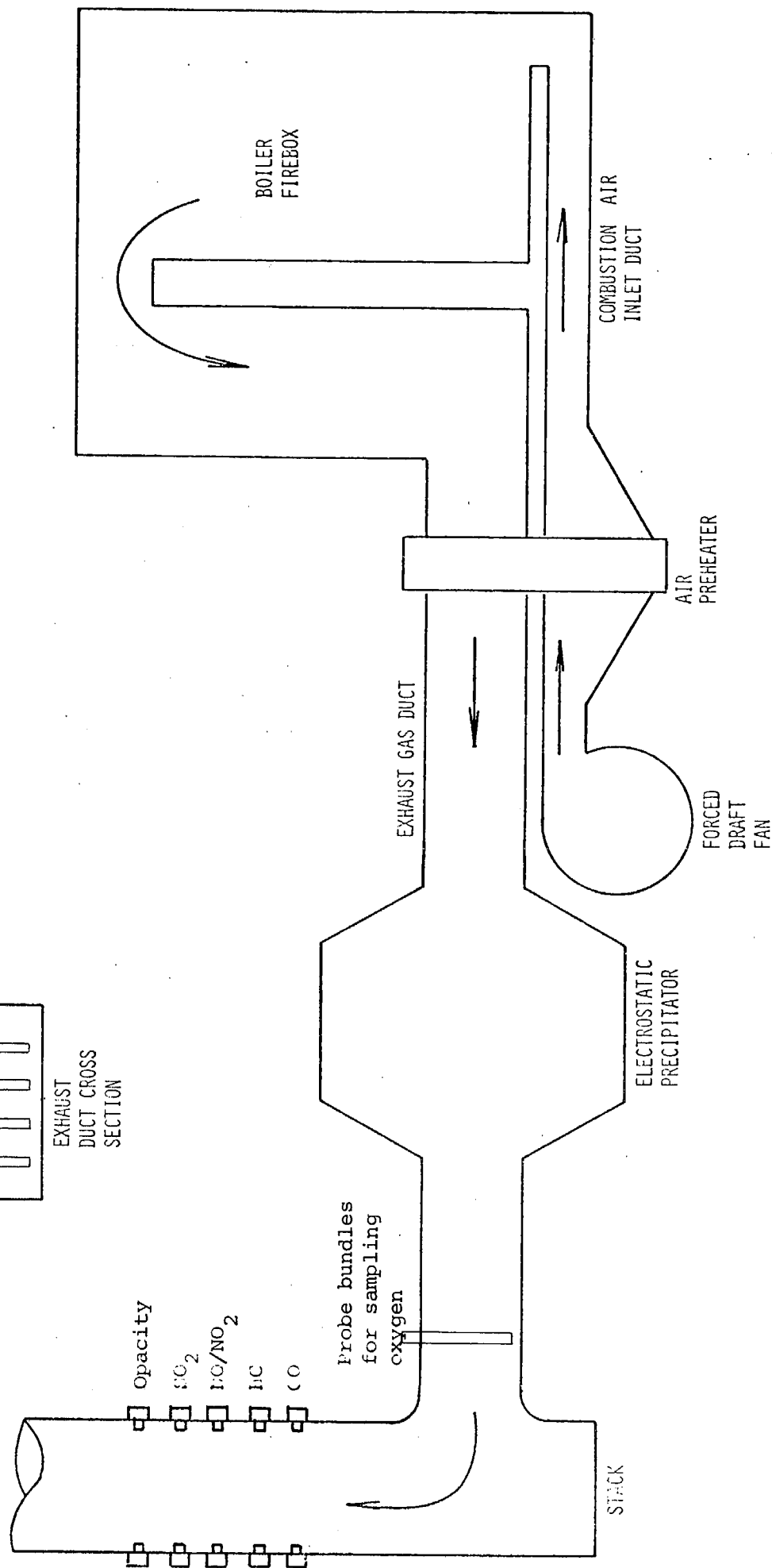
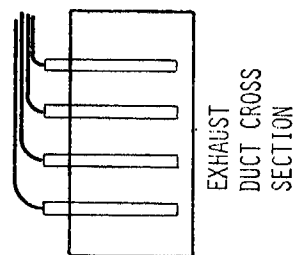


FIGURE 15. COMPLETE IN-STACK SYSTEM: IN-STACK ANALYZERS, OXYGEN  
PROBES, AND SAMPLE LINES.

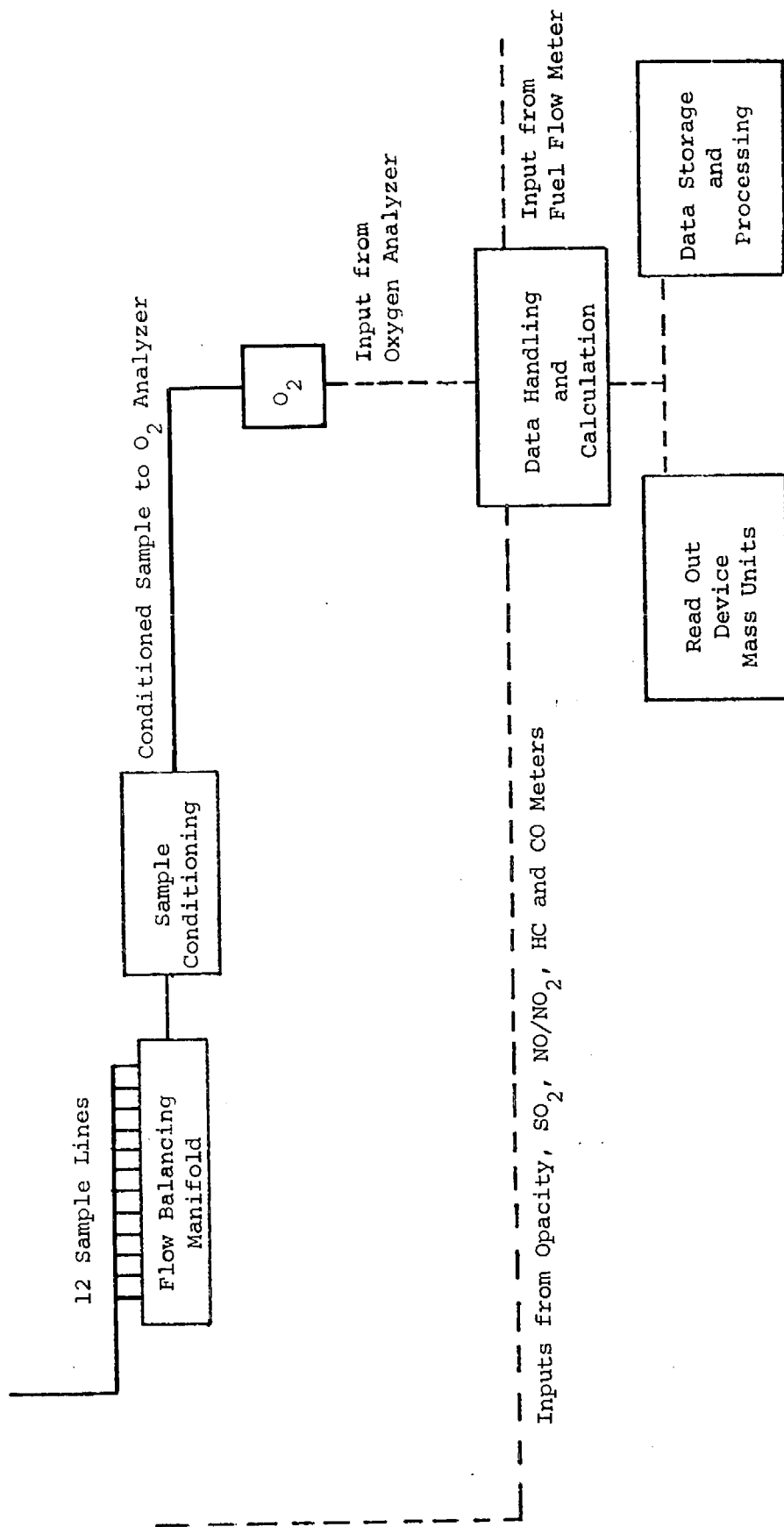


FIGURE 16. COMPLETE IN-STACK SYSTEM: O<sub>2</sub> SAMPLE HANDLING, INPUTS FROM IN-STACK ANALYZER AND FUEL FLOW METER; AND DATA HANDLING.

Both NO and NO<sub>2</sub> can be measured but this requires either two instruments, or one instrument that measures NO and NO<sub>2</sub> alternately. That is, NO and NO<sub>2</sub> cannot be measured simultaneously.

All instruments in this system are calibrated automatically.

The data handling system is similar to that for the complete extractive type system.

#### 6.4 Minimum In-Stack System (Figures 17 and 18)

The basic difference between this in situ system and the previous system is that the stack mass flow is determined by measuring the stack velocity rather than fuel flow and excess O<sub>2</sub>. As in the case of the Minimum Extractive System, the data is recorded on a strip chart recorder. The same data handling problems exist here as do in the Minimum Extractive System.

#### 6.5 Fuel Cost Savings

As was pointed out in Section 6.1, frequently a well-designed monitor system can help solve combustion problems by locating bad burners. A more direct benefit is available when O<sub>2</sub> (oxygen), CO, and HC monitors are available. Since these systems continuously monitor the basic combustion parameters, the operator can fine tune the combustion process to optimize fuel economy.

When a combustion process produces CO or HC or both, the fuel is being incompletely burned and therefore, less than full heating value is being obtained. In addition to the safety hazards which result from these pollutants being present, fuel efficiency is lowered because of the incomplete combustion.

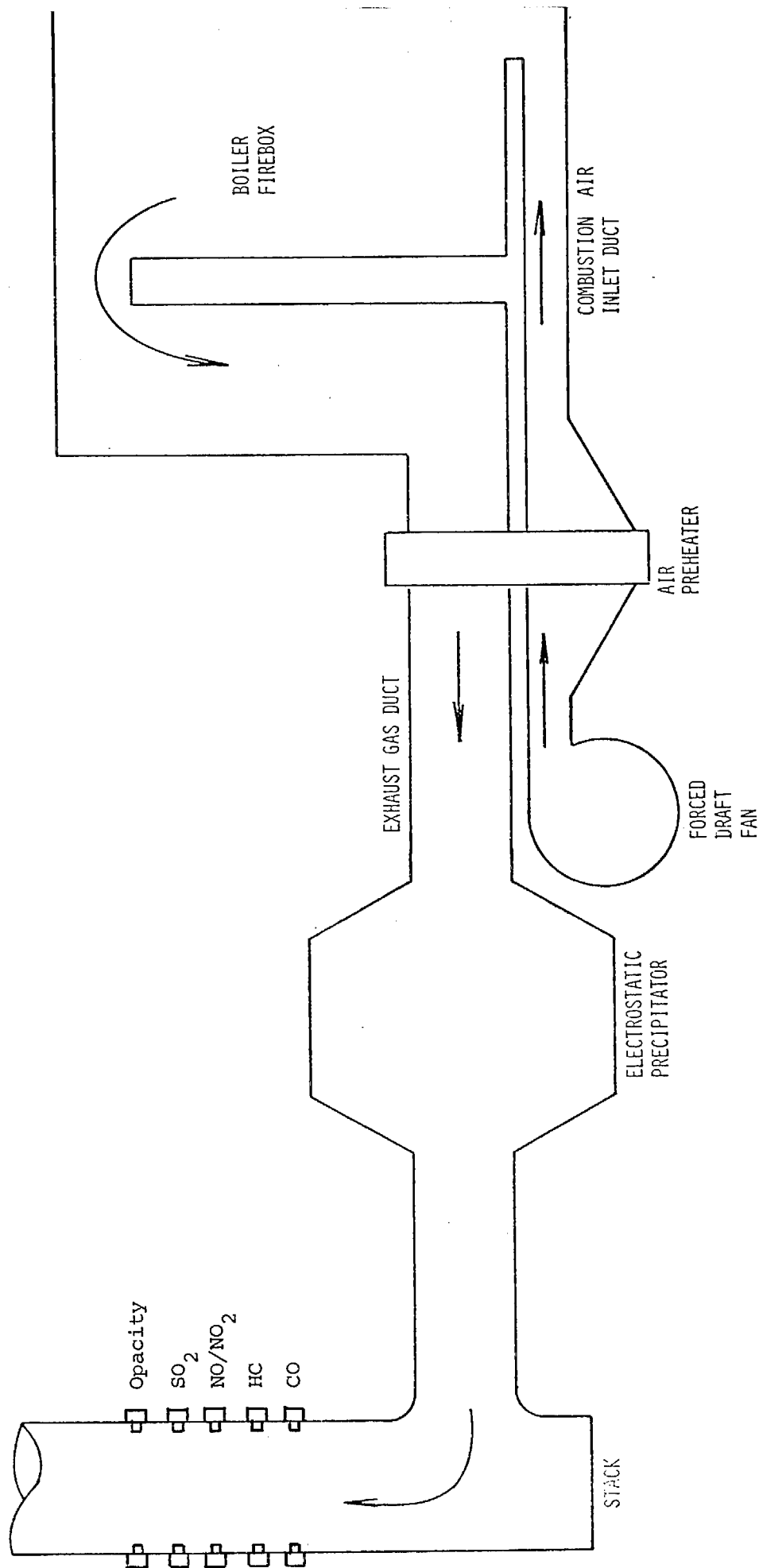


FIGURE 17. MINIMUM IN-STACK SYSTEM: PITOT AND IN-STACK ANALYZERS.

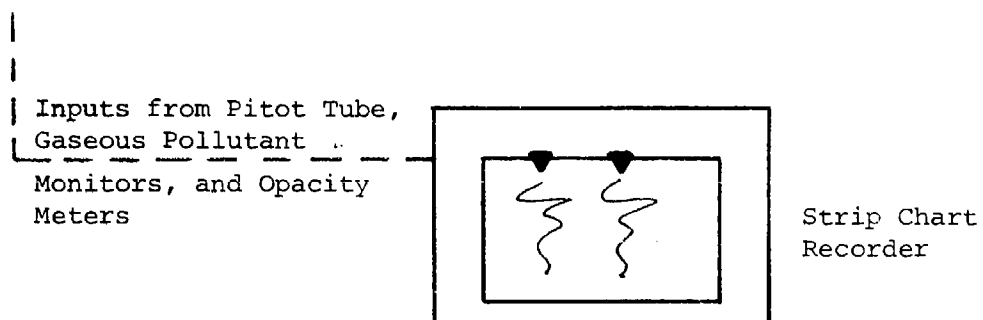


FIGURE 18. MINIMUM IN-STACK SYSTEM: DATA RECORDING



The amount of heat that is lost due to high CO levels can be estimated from Figure 19. For example, if an oil-fired 80 MMB/h boiler (~68,000 lbs steam/h) runs at 80% load, 80% of the year, it will burn about 71,000 barrels of oil in a year. If the CO level is reduced from 5000 ppm (0.5%) to 0 ppm (0.0%), approximately 2.7% of that fuel would be saved. The fuel savings would be 1917 barrels, or about \$19,000 (at a cost of \$10/bbl). Similarly, according to Figure 20, at a stack temperature of 300 ° F, if the O<sub>2</sub> level could be reduced from, say, 9.5% (80% excess air) to 3.6% (20% excess air), the fuel savings would amount to 1775 barrels, or about \$18,000. (The savings due to reduced O<sub>2</sub> levels were calculated assuming that the stack temperature would remain the same; in fact, the stack temperature would probably increase slightly and therefore, the savings would be slightly less. However, the general trend remains the same.)

#### 6.6 Procedure For Implementing Continuous Monitoring

This section presents an outline of a typical sequence of events between the time the notification is received from a regulatory agency that a continuous monitor is required though the time an operating system is on line. This outline is not intended to be a check list, but more of a starting point for those who have limited knowledge of the types of decisions that need to be made, the types of problems likely to be encountered and the requirements regarding installing and operating a continuous monitor system.

Determine and/or verify that a continuous monitor system is required.

- o In cases where the monitor requirements are stated in terms of device size, determining applicability of the requirements are straight forward. However, in cases where the requirements are stated in terms of actual emission rates, it may be advisable to conduct a source test to determine the actual emission rates. Large operations sometimes have "in-house" source test capability. Others can engage outside firms that specialize in such tests. The time required to plan and conduct a series of such tests is in the 2-12 week range.

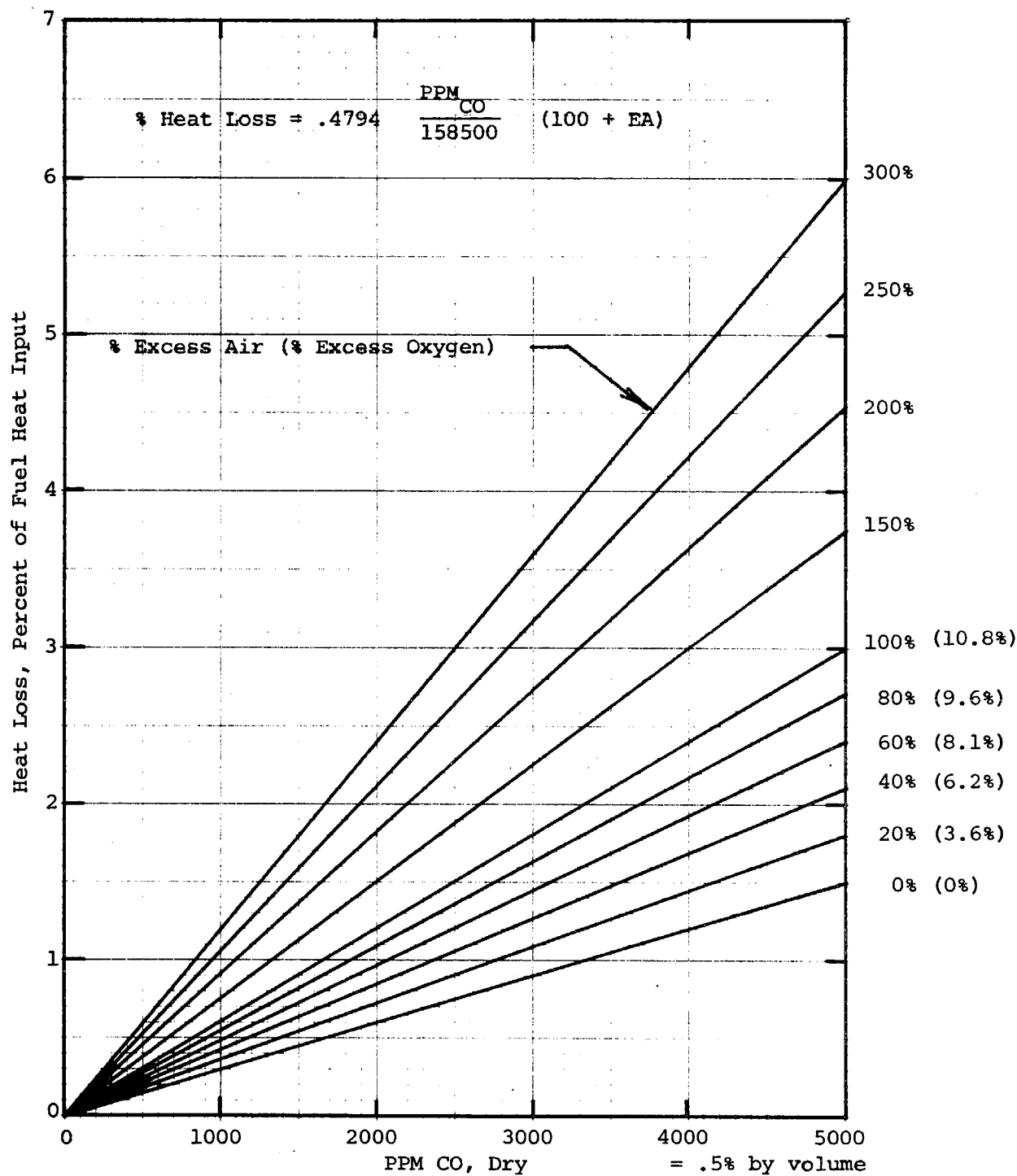


Figure 19. Effect of CO Concentration on Stack Heat Loss

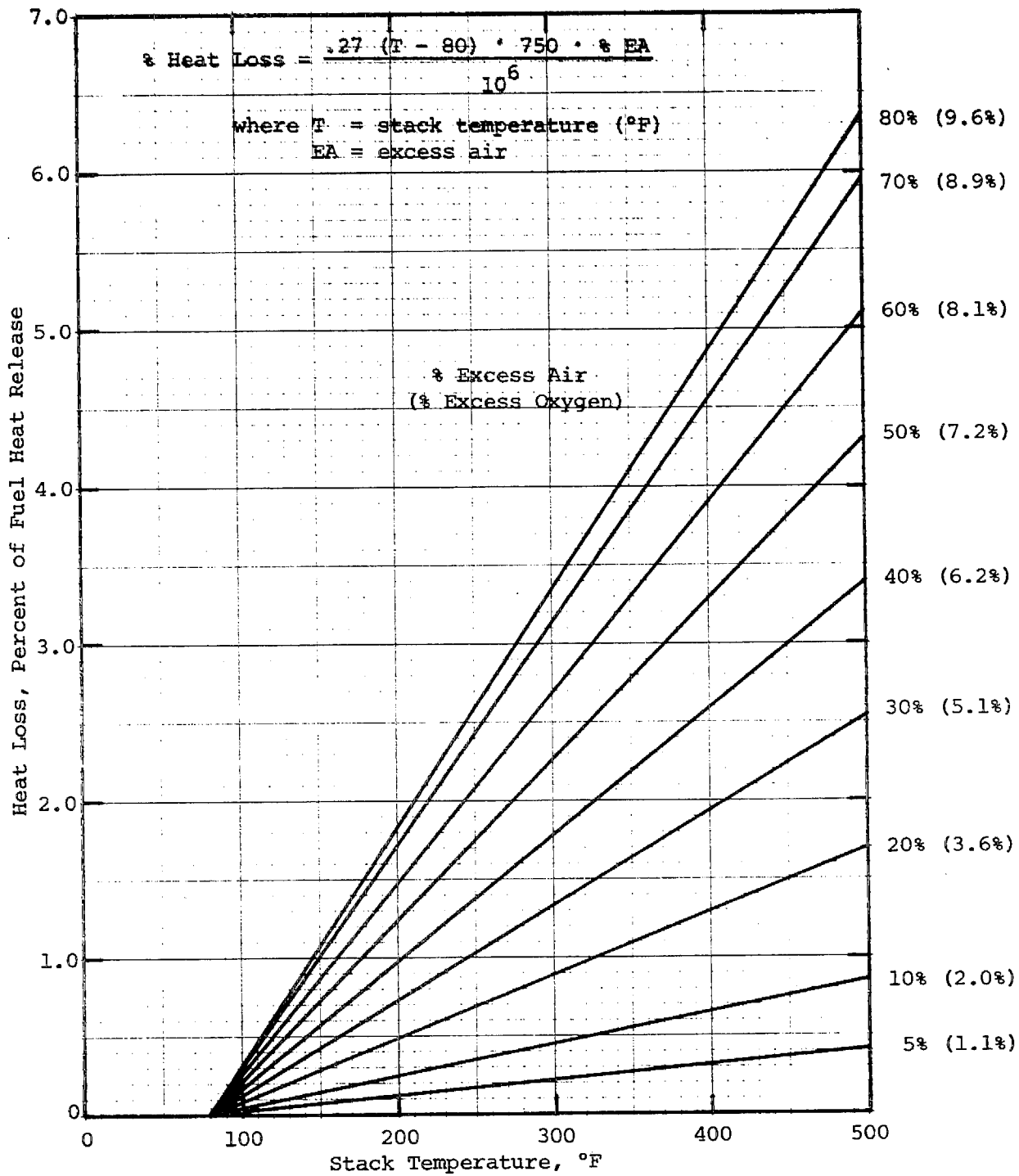


Figure 20. Effect of Excess Air on Stack Heat Loss

Once it is clear that a continuous monitor system is required the suppliers of continuous monitor systems should be contacted.

- o The suppliers can provide detailed information on types of systems available, features, costs and applicability. Once an understanding of the type equipment that is available and the costs involved is obtained, a set of functional system specifications should be prepared. Several equipment suppliers are then solicited for design and cost proposals. In selecting the monitor system, the following factors should be considered: initial cost, maintenance requirements, manufacturer's field experience, whether installation and startup are included, manufacturer's warrantee, and special features such as automatic calibration, automatic probe cleaning, etc. The system will require approval in accordance with the regulatory agency regulations.

Install monitor system and train personnel.

- o The installation will generally be done completely by the system supplier. The down time required for installation will vary considerably depending on the details of the installation. Some systems can be installed with zero down time if suitable sample ports exist. As much as 48 hours may be required for some of the more complicated in situ systems. From this standpoint it might be advisable to plan the installation to correspond with normal down times. The time and complexity of the necessary personnel training program depends primarily on the sophistication of the system that is selected. Where the most complete system is installed, the only substantial manpower requirements are those involved with the periodic maintenance of the system and replacement of the data storage tapes. ] Where a minimum system is installed, in addition to the routine maintenance requirements, personnel must be trained and made available to calibrate the system very frequently (say, every 2 to 8 hours) and extract, reduce, and record the emissions data.

Final check of the system accuracy including comparison between monitor system and reference method.

- o The proposed EPA monitor regulations<sup>(3)</sup> specify that after a 1 week conditioning period, a test of the monitor systems against a reference method will be required to assure that the system is accurately measuring the emissions.

At this point the system is on line and operating.

Periodic calibration and maintenance will be required in accordance with the manufacturer's specifications and regulatory agency regulations.

## 7.0 CONCLUSIONS AND RECOMMENDATIONS

A series of conclusions regarding the technical and economic feasibility of continuously monitoring the five major pollutants is presented in this section. Additionally, a series of recommendations is presented which will help minimize the technical difficulties associated with installing a large number of continuous monitors and efficiently using the data that is generated.

### 7.1 Conclusions

Of approximately 1300 devices emitting more than 100 tons/year of the pollutants considered, about 700 devices could effectively employ continuous monitors.

- o In most of the remaining sources it is difficult to measure the pollutants because they are not emitted from a stack or other localized point. For example, HC emissions from oil storage tanks occur from vents and from the seal at the perimeter of the floating roof. Since these emissions are spread over a relatively large area, monitoring them is essentially an ambient air monitoring task. Although in principle, an ambient air monitoring system could be designed which would monitor emissions from these sources, the cost for a system to measure even one pollutant is estimated to be very high (approximately \$120,000).

In the case of other sources, a concentration measurement is possible but a mass flow measurement is very difficult. Devices of this type are those that have a localized emission point but no stack in which to measure the exit velocity and no reliable method to measure fuel flow. For example, waste wood or Teepee burners have no stack as such (just an opening in the top of a teepee-shaped incinerator) and the wood feed rate and composition is highly variable.

Highly reliable and moderately priced (relative to pollution damage costs or fuel costs) continuous monitor systems to measure particulates, opacity, SO<sub>2</sub>, NOx, hydrocarbons, and CO are available.

- o All the components (sample acquisition, data handling, and analysis components) are available on an "off-the-shelf" basis to measure the concentration of the five major pollutants. These components are, to a large extent, well tested, and are used on a day-to-day basis in numerous locations. The experience in designing systems for most situations is extensive, as is experience in long-term operation of these types of systems. Several manufacturers offer such systems and a competitive situation exists.

The costs of continuous monitor systems range from \$5,000 to \$40,000 depending on the application. The average for a single gaseous emission measurement (SO<sub>2</sub>, NOx, HC, or CO) is about \$10,000, and for particulate measurement, is about \$20,000. For additional capabilities (additional gaseous measurements), the cost per measurement will usually go down. These costs can be compared to average pollution damage estimates of \$40,000 to \$240,000 per year per device. For a 250 MMB/h combustion device, the monitor cost can be compared to an annual fuel cost of about \$2,500,000.

"Off-the-shelf" components can be used to determine pollutant mass flow rate.

- o Mass flow rate of pollutants can be determined by measuring their concentration and the volumetric flow rate of the exhaust gas stream. The concentration levels of the various pollutants is measured by the analyzers. The volumetric flow rate can be determined by at least two different methods.

First, the velocity of the exhaust gas stream can be measured using pitot tubes (the preferred method for flue gas measurements), vane type meters, propeller meters, and thermal meters. With the velocity of the stack gas at several locations plus the temperature of the gas at these locations, the mass flow rate can be calculated.

Second, with the fuel flow rate and the oxygen content of the fuel gas, the mass flow rate can be calculated. This procedure can, of course, be used only in combustion devices.

Standard process industry components can be used to convert these analog signals into emission mass flow rates in real time for a cost that is a small fraction of the monitor cost.

Data management will be a major problem if the reading frequency and archive requirements of the EPA or the State of California are adopted and if a manual data management approach is used.

- o As was pointed out in Section 5, the amount of data generated by a continuous monitor is so very large, manual data reduction and storage is virtually impossible. To interpret, reduce, and record the 600,000 data points generated by a typical system per year would require five people working full time reducing data at the rate of one data point per minute. It appears, then, that an automatic data processing system of some type is required for even the simplest system (a system which measures an emission four times an hour would require the processing of 70,000 data points a year or approximately one man year of data reduction time).

Electronic data processing and storage of continuous monitor data can be accomplished with "off-the-shelf" components.



- o For \$5,000 to \$9,000, a complete data acquisition, reduction, and storage system can be assembled. A system such as this will eliminate any manual manipulation of the data other than changing and storing magnetic tape cassettes. For approximately \$400 per month per unit additional, a centralized storage and report preparation service could be obtained. With this system (which has applications where several devices are adjacent), the required emission reports for several devices would be generated automatically in addition to storing the data.

## 7.2 Recommendations

Format and equipment standards for electronic data handling, storage, and report preparation should be established by the cognizant government agency at an early date.

- o As was pointed out in Section 5, the large amounts of data that will be generated by even the simplest monitor system which complies with the EPA proposed sampling frequency will probably make some type of automatic data processing system necessary. Since there are numerous data processing systems that can be assembled from existing components, it is probable that very many non-compatible monitor data processing systems would be developed.

The confusion and inefficiency that would result from having a number of non-compatible systems could be prevented by a set of standards that would: (1) allow and/or require that certain plants (probably those with large numbers of devices) submit the necessary emission reports on industry-compatible magnetic tape, and (2) specify the format of the data tapes. Of course, the costs of installing and maintaining the necessary data processing systems could be prohibitive for the smaller sources.

The result of establishing these standards would be that, when feasible, facilities that have adequate data processing capabilities would be spared the expense of

manually preparing detailed reports. An additional advantage is that the emissions data would be in a form that could be computer processed. Studies of emission patterns, calculation of emission factors, and numerous other types of studies can be conducted very easily and inexpensively. In short, vast amounts of information that do not now exist would be readily available.

A test to verify the accuracy, reliability, and general adequacy of each individual continuous monitor installation should be required.

- o Since each installation presents its own unique installation problems, in order to verify that the system correctly determines the emissions in each installation, a complete evaluation of the system seems necessary.

A two-phase evaluation procedure similar to that used by several of the local air pollution control districts with regard to construction of new sources appears advisable. Phase I would be an engineering evaluation of the system design. In this way, obvious deficiencies could be noted and corrected prior to beginning installation of the system. Phase II would require an operational evaluation; that is, a series of tests would be required to confirm that the monitor system accurately measures and records the emissions over the entire normal operating load or throughput rate of the device.

Periodic inspection and recalibration of each system should be required to assure proper maintenance of the entire system (for extractive systems this includes probes, line heaters, filters, and instrumentation).

- o Since the accuracy of a monitor system can be greatly degraded by poor maintenance, a periodic inspection of the entire system would assure that the

monitor systems were maintained properly. Such inspection should include examination of the probes, sample lines, sample line heaters (where required), filters, knock-outs, analyzer unit, calibration system, and data processing, recording, and storage systems.

The required frequency of these inspections can probably only be determined by experience. However, experience to date has shown an interval of one month to be a viable period. The interval can be shortened or lengthened as experience deems necessary.

## 8.0 SUMMARY

A tabulation of sources emitting 100 tons/year or more of one or more of the five major pollutants (particulates, sulfur dioxide, oxides of nitrogen, hydrocarbons, or carbon monoxide) was compiled. These sources (about 1300) were categorized by industry type and the estimated emissions from each category were summarized.

A summary of available information on most current continuous monitor systems was compiled which describes the operating principles, advantages and costs of each type.

A scheme for converting emission rates in concentration units to mass flow units by using "off-the-shelf" components was devised. Some of the techniques and difficulties in determining mass flow rate were discussed.

An examination was made of the difficulties that will occur in the handling of the large amounts of data that continuous monitors will generate. Some schemes for using "off-the-shelf" electronic data processing components to automate the data handling process were presented.

Some typical installations were discussed, describing the major components of continuous monitor systems, and showing how they integrate with the system.

A number of conclusions and recommendations regarding continuous monitoring systems and how the problems associated with installation of large numbers of these devices can be minimized, were presented.

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APPENDIX

<u>COMPANIES SURVEYED</u>	<u>RESPONDED TO QUESTIONNAIRE</u>	<u>SYSTEMS AVAILABLE</u>
Environmental Products Division Whittaker Corporation 9100 Independence Ave. Chatsworth, CA 91311	No	NOx, SO <sub>2</sub>
International Biophysic Corporation 2700 Dupont Drive Irvine, CA 92664	No	----
CEA Instruments 555 Madison Avenue New York, NY 10022	Yes	SO <sub>2</sub>
Scott Research Laboratories, Inc. Plumsteadville, PA 18949	No	----
Intertech Corporation 19 Roszel Road Princeton, NJ 08540	No	----
Theta Sensors, Inc. 1015 No. Main St. Orange, CA 92667	No	----
REM Scientific, Inc. 2000 Colorado Ave. Santa Monica, CA 90404	No	----
Beckman Instruments Process Instruments Division 2500 Harbor Blvd. Fullerton, CA 92634	Yes	NOx, SO <sub>2</sub> , NOx + SO <sub>2</sub> , HC, CO
Environmental Data Corporation 608 Fig Monrovia, CA 91016	Yes	NOx, SO <sub>2</sub> , NOx + SO <sub>2</sub> , HC, CO, Opacity
Lear Siegler, Inc. Environmental Technology Division One Inverness Drive East Englewood, CO 80110	Yes	Opacity, Particulate

<u>COMPANIES SURVEYED</u>	<u>RESPONDED TO QUESTIONNAIRE</u>	<u>SYSTEMS AVAILABLE</u>
Thermo Electron Corp. c/o Environmental Instruments Division 85 First Ave. Waltham, MA 02154	No	----
Leeds & Northrup Company 1360 So. Anaheim Blvd. Suite 225 Anaheim, CA 92805	No	----
E.I. DuPont de Nemours & Co. (Inc.) Instrument Products Division 1500 So. Shamrock Monrovia, CA 91016	Yes	NOx, SO <sub>2</sub> , NOx + SO <sub>2</sub>
Mine Safety Appliances Co. 7100 Fair Ave. North Hollywood, CA 91605	Yes	NO, SO <sub>2</sub> , NO + SO <sub>2</sub> , HC, CO
Western Research & Development Ltd. 932 Pacific Plaza Calgary Alberta T2P0T8 Canada	No	----
Forney Engineering Co. P.O. Box 189 Addison, TX 75001	Yes	Opacity
Bailey Mater Co. 29801 Euclid Ave. Wickliffe, OH 44092	No	----
GCA Technology Div. Burlington Rd. Bedford, Mass. 01773	Yes	Particulate
KVB Equipment Corporation 1306 E. Edinger Ave., Suite A Santa Ana, CA 92705	Yes	NO, SO <sub>2</sub> , NO + SO <sub>2</sub> , HC, CO

## AIR RESOURCES BOARD

1709 - 11th STREET  
SACRAMENTO 95814



KVB, Inc. has been awarded a contract by the State of California Air Resources Board to develop criteria which can be used to assess the practicality of requiring continuous monitoring of emissions from various stationary sources.

The program will culminate in a report to the ARB and consists of four basic tasks:

- A. Classifying the sources in the State by process type, size and description;
- B. Defining the species of pollutant emitted from each classification together with emission rate;
- C. Determine the cost and feasibility of continuous monitoring for each source classification; and
- D. Provide information on the type of control equipment available for each source class.

As part of Task C, we are soliciting the cooperation of the manufacturers of continuous source monitoring equipment to provide performance characteristics and cost ranges of the various monitoring systems currently available. The inquiry is directed at both extractive and in-situ systems and is limited to complete systems rather than instruments alone, i.e., for extractive systems the complete system would include sample acquisition, sample pretreatment and sample analysis. The systems of interest are those with the capability to measure the following emissions:

- |  |                                    |
|--|------------------------------------|
| 1. NO <sub>x</sub>                     | 5. CO                              |
| 2. SO <sub>2</sub>                     | 6. Particulates in terms of weight |
| 3. NO <sub>x</sub> and SO <sub>2</sub> | 7. Opacity                         |
| 4. Hydrocarbons                        |                                    |

We would appreciate any information which you can provide KVB regarding monitoring equipment manufactured by your company which measures the above parameters. Enclosed is a questionnaire which will provide the desired information for the study. Your cooperation in completing the form and returning it to the following address: KVB, Inc., 17332 Irvine Blvd., Tustin, CA. 92680, will be greatly appreciated.



If you have any questions or require additional information, please do not hesitate to contact Mr. Wallace A. Carter of KVB at (714) 832-9020.

Sincerely,

A handwritten signature in cursive script, appearing to read "A. H. Bockian".

A. H. Bockian, Ph.D.  
Acting Chief,  
Research Section

Enclosure

## QUESTIONNAIRE

1. Pollutant Measured: Information is desired for systems with the capability to measure each of the following:

1. NOx
2. SO<sub>2</sub>
3. Both NOx and SO<sub>2</sub>
4. Hydrocarbons
5. CO
6. Particulates in terms of weight
7. Opacity

Please submit a separate completed questionnaire for each category for which you have capability.

2. Principle of Operation: Instrument technique used to detect and measure pollutant.
3. Method of Operation: Is system continuous or intermittent? If intermittent, what is cycle?
4. Description of System Components:  
Sample Interface - That portion of the measurement system that performs one or more of the following operations: delineation, acquisition, transportation, and conditioning of a sample of the source effluent or protection of the analyzer from the hostile aspects of the sample or source environment.  
  
Analyzer - That portion of the system which senses the pollutant gas and generates a signal output that is a function of the pollutant concentration.  
  
Data Presentation - That portion of the measurement system that provides a display of the output signal in terms of concentration units.
5. System Performance
  - a. Range: The lower and upper detectable limits.
  - b. Accuracy: The degree of correctness with which the measurement system yields the value of gas concentration of a sample relative to the value given by a defined reference method. This accuracy is expressed in terms of error which is the difference between the paired concentration measurements. The error is expressed as a percentage of the reference mean value.
  - c. Calibration Error: The difference between the pollutant concentration indicated by the measurement system and the known concentration of the test gas mixture.

- d. Zero Drift: The change in measurement system output over a stated period of time of normal continuous operation when the pollutant concentration at the time of the measurements is zero.
- e. Span Drift: The change in measurement system output over a stated period of time of normal continuous operation when the pollutant concentration at the time of the measurements is the same known upscale value.
- f. Repeatability: A measure of the measurement system's ability to give the same output reading(s) upon repeated measurements of the same pollutant concentration(s).
- g. Response Time: The time interval from a step change in pollutant concentration at the input to the measurement system to the time at which 95 percent of the corresponding final value is reached as display on the measurement system data presentation device.
- h. Operational Period: A minimum period of time over which a measurement system is expected to operate within certain performance specifications without unscheduled maintenance, repair or adjustment.

## 6. Operational Requirements

- a. Ambient Temperature Range: The range of ambient temperature over which the system will meet stated performance specifications.
  - b. Calibration: The method for determining the system response to calibration gases, i.e. dynamic calibration using real gases or artificial stimuli (static using devices such as optical filters calibration).
  - c. Warm-up Time: The elapsed time necessary after start-up for the system to meet stated performance specifications when the system has been shut down for at least 24 hours.
  - d. Maintenance Requirements: Description of regular, scheduled maintenance required by the complete system together with frequency of maintenance, and usage rate of system expendables.
- 7. System Requirements: electrical power; voltage and power air; flowrate, pressure, condition water; flowrate, pressure, condition
  - 8. Physical Characteristics: Approximate dimensions and weight
  - 9. Approximate Cost:
  - 10. Features: Description of distinctive system characteristics or capabilities.

